Chapter - 7

CONCLUSIONS
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- The area around Lakkireddipalle in the southwestern margin of the Cuddapah basin where the fracture-controlled uranium mineralisation occurs, is largely occupied by the granitoids which are emplaced by dolerite dykes and dissected by fracture system. Two phases of granitoids are identified. Peninsular gneisses form the peneplane area where as younger granitoids of Closepet granite equivalents form ridges and mounds. Uraniferous fracture zones are associated with the younger granitoids (pink and grey colours) containing higher intrinsic uranium.

- Three sets of major fracture systems, viz. ENE-WSW, NNE-SSW and NW-SE trending fractures are reported (Vasundara Project). ENE-WSW trending fractures are more pronounced around Lakkireddipalle where as NNE-SSW trending and NW-SE trending fractures are predominant in the eastern and western part of Lakkireddipalle respectively.

- The field and the geological guides for exploration of fracture controlled type of uranium mineralisation in the study area can be broadly grouped in to three general categories, viz. (1) Topographic guides (2) Mineralogical guides and (3) Structural guides.

- The fracture zones form rectilinear ridges, well pronounced in areas of Peninsular gneisses due to the low relief, and less pronounced in areas of granites forming hills and mounds.

- The mineralogical guides include alterations identified based on colour, texture and their spatial relation to the fracture zones. The alterations observed are mainly haematitisation, silicification, chloritisation, sericitisation,
apatitisation and argillisation. These are not necessarily associated with all the fracture zones, rather a combination of two or rarely three are prevalent in a single fracture zone.

- Structural guides include closely spaced fractures, development of cataclasite and mylonite.

- Radiometric examination of the different rock types shows granitoids of Peninsular Gneissic Complex records 20 mR/h where as the pink and grey granitoids records higher background of 40 mR/h. Similarly the background radiations recorded from the basic dyke rock is still less i.e 10 mR/h. This variation in the radiation recording is attributed to the intrinsic content of radioactive elements like U and Th.

- Petrographically, gneisses are composed mainly of quartz, in addition to feldspars, hornblende, epidote and chlorite with minor zircon, sphene, apatite. They fall in monzogranite-granodiorite-quartz monzodiorite fields. They are metaluminous to peraluminous in nature recording alumina saturation index values ranging from 0.74 -1.42 with an average of 1.1 and normative corundum (norm $C = 1.1\%$ on an average). The samples of gneisses of the study area define a typical calc-alkaline trend on an AFM diagram.

- Variation diagrams of the Peninsular gneisses with whole rock SiO2 reflect linear trends and negative correlation with TiO$_2$ ($r=-0.92$), MgO ($r=-0.86$), CaO($r=-0.92$), P$_2$O$_5$ ($r=-0.94$), FeO (-0.91) and Al$_2$O$_3$ pointing towards igneous character of the gneisses. Poor correlation of SiO$_2$ with the alkalis K$_2$O ($r=0.096$) and Na$_2$O (-0.03) may be attributed to alteration of feldspars.

- Distribution of trace elements like Rb,Ba and Sr content shows these gneisses are poorly differentiated rock types.
Petrographic and geochemical studies of granites of the study area indicate that they are porphyritic to even-grained monzogranitic to granitic with microcline microperthite, biotite and chlorite. Accessory minerals are zircon, titanite, allanite, apatite, epidote, and magnetite. Biotite is normally partially chloritized. On Q-A-P diagram, based on modal composition, all the samples fall in the field of monzogranite and based on normative composition they fall between syeno-granite to monzogranite.

The chemical data suggest that granites of study area are per-aluminous (A/CNK ranging from 0.96 to 2.44 with an average of 1.22) and corundum normative (1.3 vol%). On the basis of alkalinity ratio, the granitic and gneissic rock of the study area fall in the calc-alkaline field.

Variation diagrams of the granites with whole rock SiO₂ reflect linear trends and negative correlation with TiO₂ (r = -0.46), MgO (r = -0.45), Al₂O₃ (-0.79), Fe₂O₃ (-0.49), FeO (-0.38) and positive correlation with P₂O₅ (0.49)

Poor correlation of SiO₂ with CaO (0.15), Na₂O (0.19) and negative correlation with K₂O(-0.58) may be attributed to alteration of feldspars.

TiO₂, FeO(total). MgO and CaO are generally low reflecting the leucocratic nature of the granite and reasonably evolved stage of differentiation. In all samples K₂O predominates over Na₂O. The average K₂O /Na₂O ratio is 2.2.

Trace element data of Rb-Ba-Sr indicate the granites of the study area to be strongly differentiated. The Rb/Sr ratios (range 0.2 to 15; average 5.27) and K/Rb ratios (range 85 to 282 average 195) indicate a fairly evolved granite in agreement with other differentiation Indices.
Brecciated granite samples show a complete change in the overall chemistry compared to their protolith. Among the major oxides, major changes are indicated by enrichment of TiO₂, Fe₂O₃, MnO, CaO, P₂O₅, and LOI. All the samples lost their original granitic composition identity and all the samples fall on alkali granite and tonalite fields. This is due to the intense alterations of the protolith granite. Retention of magmatic character of the brecciated granite is indicated by the negative correlation of SiO₂ with TiO₂, Al₂O₃, MgO, FeO, and CaO. Lack of correlation between SiO₂ with Na₂O and negative correlation of SiO₂ with K₂O may be attributed to the alterations. This is also supported by the substantial increase in LOI.

Mylonite/phyllonites in the shear zones hosted by the granites in the study area are typically dark green, grey to black colored, largely aphanitic, and massive. Both in hand specimen and under the microscope, the mylonites are characterized by well-developed S–C fabrics which are defined by variation in colour and preferred orientations of fragments.

Mylonite consists of quartz and feldspar grains occurring as porphyroclasts in the matrix. Two types of quartz are identified namely Relict quartz and fine-grained recrystallised quartz. Fine-grained recrystallised quartz is typically elongated or smeared out into millimeter scale ribbons, defining a strong foliation. Feldspars are commonly intergrown with polygonal quartz crystals and show polysynthetic twinning, the K-feldspar loses its microperthitic texture (Fig.3.66).

The geochemical data of the mylonite samples from the fracture zone shows substantial enrichments in some major, minor, and trace elements (TiO₂, P₂O₅,
Zr, Y, and V) and depletions in SiO₂, K₂O, Na₂O, Rb, Ba and Sr relative to the protolith.

- Study of the samples collected across the fracture zone to understand the changes in the bulk chemical composition of the rock types during transformation of protolith-granite to mylonites during the deformation indicates depletion of mobile elements such as SiO₂, K₂O, Na₂O, CaO and other, enrichment of immobile elements like TiO₂, Fe₂O₃, MgO, FeO and P₂O₅. Similarly trace elements like Rb, Sr, Ba shows depletion and Zr, Co, Cr and Cu shows enrichment in the mylonites. The transition from the unaltered granite to altered granite samples is marked by decrease in sodium, calcium, increase of potassium and Ferric iron. This alteration signature is associated with the destabilization of feldspars and biotites. Chondrite normalized rare earth element (REE) patterns for individual rock types show slopes for unaltered and altered samples are similar, suggesting that the alteration process did not cause marked fractionation of the rare earth elements.

- Uranium in the fracture zones occur as discrete uranium phase (a) ultrafine pitchblende, coffinite, brannerite and U-Ti complex associated with specular hematite and limonite, (b) in the adsorbed state on limonite, smectite and chlorite (c) as secondary uranium minerals like autunite and uranophane and in accessory minerals like apatite, leucoxene, anatase, sphene, allanite, zircon and monazite.

- The correlation between fracture development and uranium mineralization in the basement granites of study area shows that the formation of the uranium deposit involved a multiphase cataclastic/hydrothermal event.
Uranium mineralisation is associated with alterations like haematitisation, chloritisation, sericitisation, silicification, and phosphatisation. Petrographic evidence indicates that both alteration and uranium mineralization were episodic in nature, suggesting that mineralized cataclastic zones acted as channel-ways within which hydrothermal fluids flowed cyclically during deformation.

Intense cataclasis and brecciation associated with the fractures/shears helped oxidizing fluids cyclically circulated through the fault zone during epithermal processes. After leaching the uranium from the source rocks uranium enriched fluids may have been channeled into the zone of brecciated granites and mylonites. Where fluid bearing fracture zones intersected the reducing physico-chemical conditions, uranyl complexes in the fluid would react and lead to the precipitation of the ore assemblages.

Uranium ore assemblage consisting of uraninite and pitchblende, and the abundance of titanium bearing uranium minerals like brannerite, anatase and phosphate bearing minerals like apatite and absence of calcite in the primary uranium ore assemblage, indicates that, mineralization process uranium was probably transported primarily as phosphate, oxide and/or fluoride complexes.

Synthesis of the geology, structure, and whole rock geochemistry suggest that the uranium mineralisation took place through fault controlled fluid circulation in the granites of Closepet granite equivalents. Uranium mineralization associated with the fracture/shear zones in the granites involved three stages: (1) formation of fertile granites (2) alteration of granites and release of uranium during cataclasis (3) development of mylonites and precipitation of uranium.