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Diagenetic evolution of onshore Campanian Sandstone, Ariyalur-Cauvery Basin

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Abstract: The onshore Campanian (Sillakkudi Fm.) sandstone consists of sub-angular to angular grains which composed of quartz (97%), feldspar (2.5%) and lithic fragments (0.5%) of continental block provenance derived by the rapid rate of erosion under hot and humid climate. The fabric signifies the free-floating (33%), point (46%), long (17%), sutured (2.5%) and concavo-convex contacts (1.5%). The relative high percentage of free-floating grains and point contacts by calcite cements suggesting early cementation process and diminutive compaction. Whereas the 63% of point and long contact and 4% of sutured and concavo-convex contact symptomatic of the early calcite cementation and mechanical compaction in excess of the chemical compaction.

The sandstone diagenesis is controlled by texture, detrital composition, environment of deposition and associated lithology (Burley et al., 1985; Morad et al., 2000). On a regional scale, tectonic setting of the basin, geothermal gradient, rate and extent of deposition and basin subsidence shows a role in diagenetic process. Lately, deposited sand is a porous, non-equilibrium mixture of detrital minerals and diagenetic processes tend to bring them towards equilibrium with the prevailing physical and chemical conditions, which is achieved by reduction of porosity through compaction and precipitation of stable authigenic cements or grains. The physical and chemical processes are operating simultaneously in response to the surrounding stress field to achieve equilibrium. The process of compaction and cementation results in loss of porosity as it decreases the pore space by squeezing and occluding the pore spaces present within the detrital grains, which is irreversible process. The process of diagenesis is significant in determining the reservoir quality of the rock. The Sillakkudi Sandstone has subjected to diagenetic processes such as compaction, cementation, dissolution of feldspar and clay mineral authigenesis. This study is focused in understanding the diagenetic evolution of onshore Campanian sandstone of Cauvery Basin.

Geology and stratigraphy

The Cretaceous succession of Cauvery Basin consists of a shallow marine sequence with rich faunal succession of Albian-Maastrichtian age. The Cauvery Basin is a rift basin (Rangaraju et al., 1993), developed by extension during the Mesozoic breakup of the Gondwana land (Prabhakar and Zutshi, 1993). Blandford (1862) reports this succession as Uttatur, Trichinopoly and Ariyalur Groups on the basis of lithology. Sastry et al. (1972) refers the Ariyalur Group comprises the Sillakkudi, Kallankurichchi, Ottakovil and Kallamedu Formations in upward succession. The Ariyalur Group conformably rests over the Trichinopoly Group (Table.1). The sediments of this basin are exposed on the coastal plain of Tamil Nadu, along the Ariyalur, Vridhachalam and Pondicherry. Of these, the Ariyalur area provides the complete representation of the Mesozoic succession and afforded contributions on stratigraphy, paleontology, paleoclimate and tectonic evolution of the succession (Banerji, 1979; Ramanathan, 1979; Sundaram and Rao, 1986; Ramasamy and Banerji, 1991; Ramasamy et al., 1995; Govindan et al., 1996; Madhavaraju and Ramasamy, 1999a, b; 2001; Madhavaraju et al. 2002; Ayyasamy, 2006, Nagendra et al., 2003, 2010, 2011, 2017). Except Kallamedu Formation, all the formations of the Ariyalur Group were deposited in the marginal marine environments (Sundaram and Rao, 1986; Madhavaraju and

Ramasamy, 1999b; Madhavaraju and Lee, 2009).

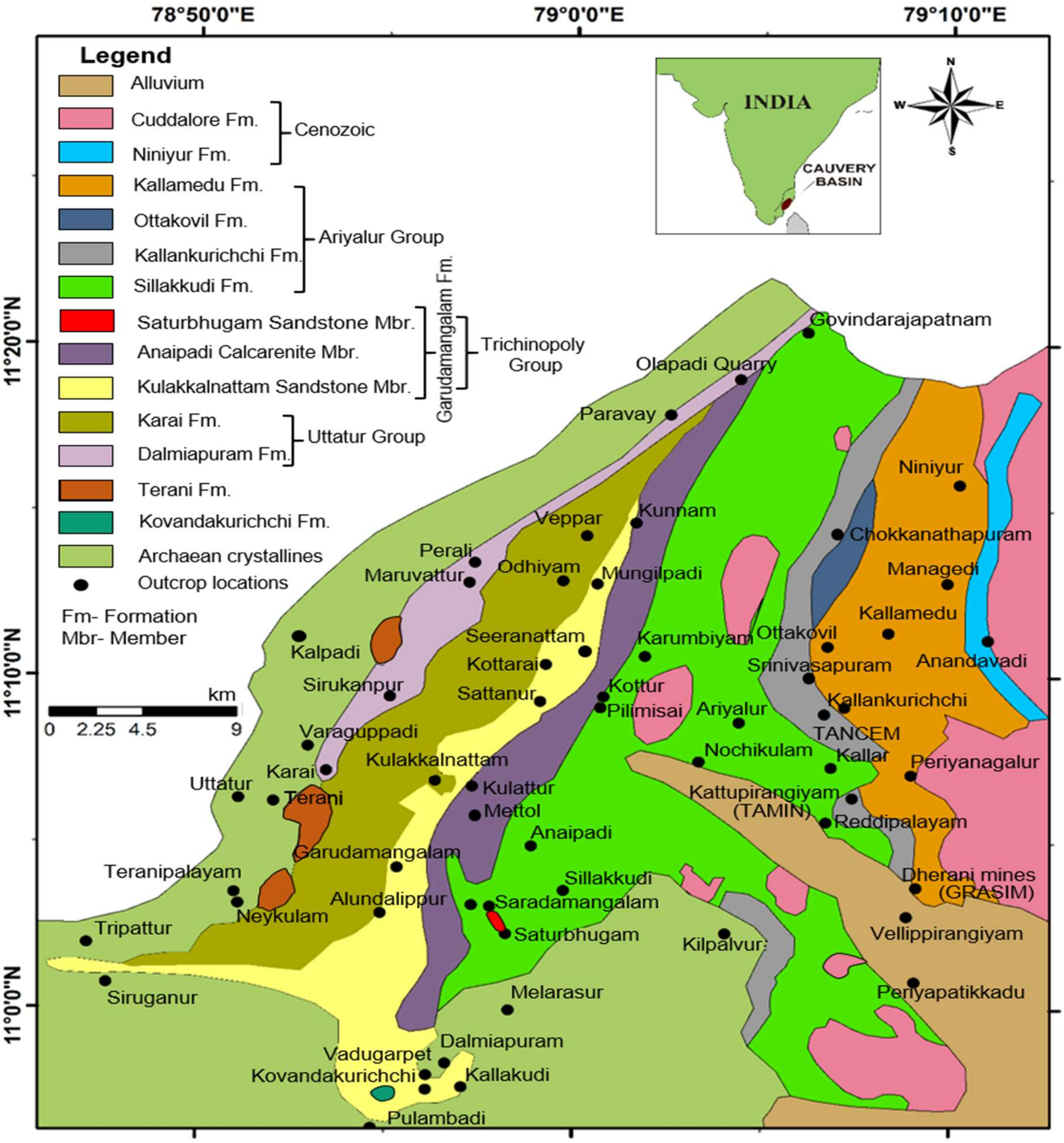


Fig.1 Geological map of Cretaceous successions, Ariyalur- Cauvery Basin

Sillakkudi Formation

The Sillakkudi Formation of Campanian age is exposed at the base of the Kallankurichchi Formation of Ariyalur Group, is addressed in this study to understand the diagenetic evolution of Campanian sandstone. (Fig.1). This formation comprises of fossiliferous calcareous gritty sandstone, calcareous sandstone and interbedded arenaceous limestone with sandy clay. The Sillakkudi Formation (Fig.1) is well-exposed in and around Mettol railway cutting (11°04'54.9"N:79°02'3.1"E),Nochikkulam 11°07'55.8"N:79°03'01"E),and Vayalpadi (11°20'2.5"N: 79°07'9.1"E) areas.

Materials and methodology

Ten sandstone samples (10m interval) sampled at Mettol railway cutting section near Sillakkudi with GPS coordinates. The macroscopic description of sandstone was evaluated qualitatively and quantitatively in the field by using 10X magnified lens. Twenty sandstone thin sections were stained for determining the type of cementation. The multiple grains were measured to its size, shape and angularity to attribute the sphericity and roundness of grains. The grain geometry, authigenic minerals, patterns, habits, pore spaces between the grains, partially filled pores, partly dissolved grains, and an abundance of mineral suites were accounted. The grid spacing method is used in point counting exceeded the grain size to avoid the individual grain to be counted more than once (Van der Plas and Tobi, 1965). The 300 numbers of gains are counted and tabulated for calculation of percentages of quartz, feldspar, and lithic fragments in identification of type of sandstone using QFL plot. To reconstruct the original detrital composition of sandstone, the effect of diagenesis was considered during the counting of QFL grains.

<table>
<tr><th>Group</th><th>Formation</th><th>Lithology</th><th>Age</th></tr>
<tr><td colspan="3">Niniyur Formation</td><td>Danian</td></tr>
<tr><td rowspan="4">A R I Y A L U R</td><td>Kallamedu</td><td>Unfossiliferous fine to coarse grained sandstones interbedded with siltstone, sandy clay, ferruginous clay and marl</td><td rowspan="3">Maastrichtian</td></tr>
<tr><td>Ottakovil</td><td>Fossiliferous calcareous sandstone interbedded with sandy clay</td></tr>
<tr><td>Kallankurichchi</td><td>Fossiliferous calcareous conglomeratic sandstone interbedded with sandy clay, sandy fossiliferous limestone, fossiliferous limestone and marl</td></tr>
<tr><td>Sillakkudi</td><td>Unfossiliferous calcareous sandstone, Fossiliferous calcareous gritty sandstone, Fossiliferous calcareous sandstones interbedded with sandy clay and thin band of sandy limestone</td><td>Campanian</td></tr>
<tr><td colspan="4">Trichinopoly Group</td></tr>
</table>

Table 1. Lithostratigraphy of Ariyalur Group (after Sastry et al., 1972)

Results and discussions

The diagenetic characteristics of the sandstones are briefly discussed below;

Mineral composition

The mineralogy of Campanian sandstones was studied to its physical and optical properties. The point counting method is used for describing the mineral grains and its population. The grid spacing method is cast-off in point-counting, to avoid the individual grain count more than once (Van der Plas and Tobi, 1965). The average composition of the detrital minerals of Sillakkudi Sandstone are quartz (97.45%), feldspar (2.41%), and lithic fragment (0.14%) including biotite mica, opaque minerals and heavy minerals (Table.2). Sillakkudi sandstone is fine to medium grained arenaceous, sub-rounded-rounded, angular and moderate to poorly sorted and is classified as quartz arenite.

Sample No	Quartz	Feldspar	Lithic fragments	Total	Quartz%	Feldspar%	Lithic Fragments %
MRC-1	287	11	2	300	95.6	3.7	0.7
MRC-2	293	7	0	300	97.7	2.2	0.1
MRC-3	296	4	0	300	98.7	1.3	0
MRC-5	291	9	0	300	97	3	0
MRC-8	295	5	0	300	98.6	1.4	0
MRC-10	297	3	0	300	99	1	0
SRC-1	291	7	2	300	97	2.7	0.3
SRC-2	289	11	0	300	96	4	0

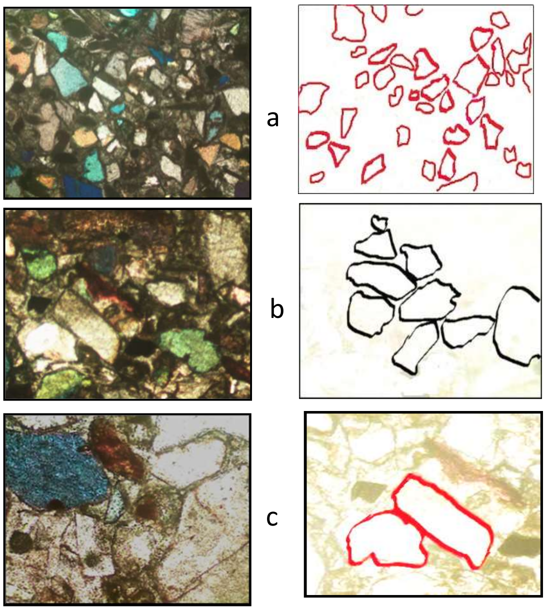
Table. 2. Sandstone composition of Sillakkudi Formation.

Compaction

Compaction process is responsible for closer packing of the detrital grains due to the pressure exerted by the load of overlying sediments (Chilingar et al., 1983). The compaction affects the well-cemented detrital grains directed by the concavo-convex and sutured contact. The inter-granular pore spaces of clastic sediments are eliminated by closer packing, crushing deformation, expulsion of fluids and dissolving of grains. The grain contact in Sillakkudi sandstone was accounted to decipher the compaction history. The detrital grains are signifying, the free-floating (33%), point contact (46%), long contact (17%), sutured contact (2.5%) and concavo-convex contact (1.5%). The 33% of floating grains indicates the early cementation of the detrital sandstone grains (Fig.2). The point contact is formed in the early stages of compaction due to mechanical process, whereas the long contact is developed because of rotation and tuning of grains to the adjoining grain boundaries whereas the sutured and concavo-convex contacts are formed owing to the dissolution of the grains along the boundaries of long contact. The Sillakkudi sandstone illustrates the effect of both mechanical and chemical compactions. The detrital grains of Sillakkudi sandstone are having contact index of 0-4. The free-floating grains, contact index are zero. The average contact index is 1.8 (Fig.3). The contact index is owed to the presence of significant number of free-floating grains which are due to early cementation process and dominance of point and long contact of the detrital sedimentary grains.

Cementation

Cementation is a diagenetic process by which new mineral is precipitated as syntaxial overgrowth in the pore spaces of the detrital sandstone grains from the intraformational saturated fluid which are circulating in the pore space. The authigenic cementing mineral identified in Sillakkudi sandstone are calcite cement ($CaCO_3$) and ferruginous cement (Fe_2O_3). 95% of the total cement is calcite precipitate in sandstone. Calcite cement distributed as oversized pore space filling and rarely in the form of patchy distribution. Calcitic cement was identified by staining the thin sections, where calcite is pinkish orange colour (Fig.4). The process of calcitic cementation might have been formed after considerable burial by



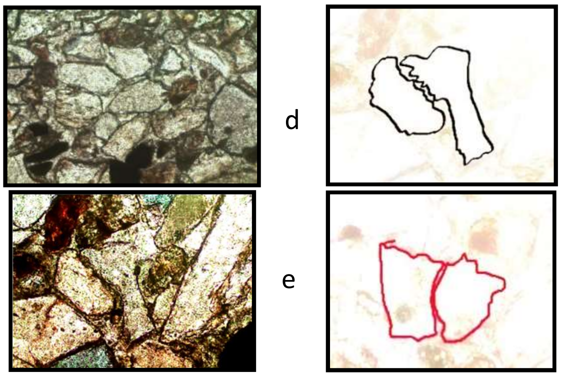
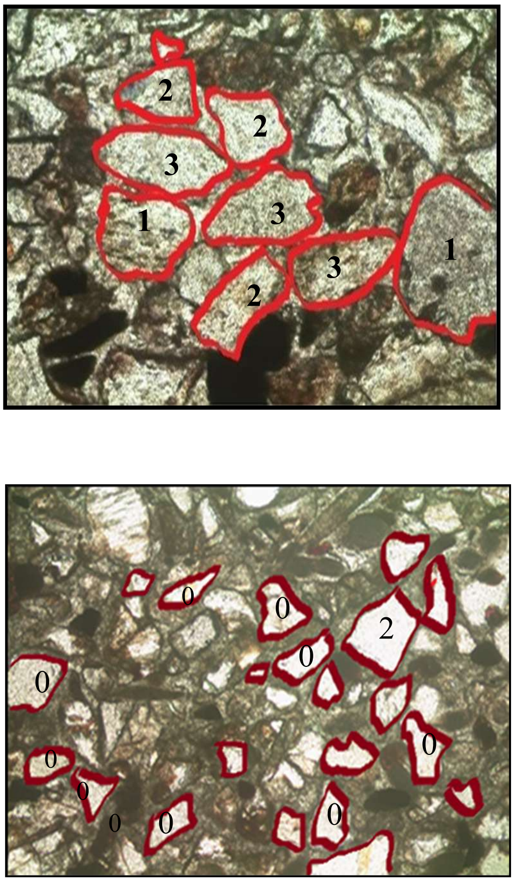


Fig 2. Sandstone fabric; (a) Free floating contact (b) Point contact (c) Long contact (d) Sutured contact (e) Concavo-convex contact

ground water saturated with calcium carbonate moving through the pore spaces. The presence of calcite cement in oversized pore spaces along with the significant number of free floating detrital grain suggests towards the early cementation of the detrital grains in Sillakkudi Sandstone, indicating that the calcite cement was hitherto deposited in a shallow water condition. It is established that the early precipitation of the carbonate cement occurs at niche water column below the sediment water interface (Bjorlykke, 1989).



Average no. of grain contacts a grain has with its neighboring grains.

Maximum value of Contact Index (C.I) was 3 whereas minimum value of Contact Index (CI) was 0.

The overall average contact index was found to be about 1.8 indicating moderate tight packing due to mechanical compaction and early cementation.

Fig 3. Grain contact index of Sillakkudi sandstone

The detrital quartz grain cemented by the calcitic cement is corroded along boundaries, characterized by ferruginous-calcitic cement. The corroded quartz grain exhibits calcite cement infilling, suggesting the presence of syn-depositional calcitic cement, which might have been replaced by the ferruginous cement during deeper burial of the detrital. The calcitic cement was responsible for reducing the porosity and permeability, affecting the reservoir property of the Campanian Sillakkudi Sandstone in Cauvery Basin.

The ferruginous cement occurs in the form of pervasive pore space filling. This is characterized by the ferruginous and calcite cement, the detrital grains are demonstrating the free floating contact, which are cemented by the calcitic cement suggesting the syn-depositional cement, which is later replaced by the calcite cement. However, the inclusion of calcitic cement in the quartz grain suggests the presence of syn-depositional calcitic cement. The ferruginous cement is characterized by the reddish brown colour in both PPL and crossed Nichols. The oversized pore spaces might have been resulted from destruction and leaching of labile framework, possibly feldspar. The total ferruginous cement in the sandstone is about 10%, derived from the weathering and leaching of ferromagnesian silicate minerals in the source area. The precipitation of ferruginous mineral from the iron saturated solution is governed both by the hydrogen ion concentration, pH and the redox potential of the environment. Drever (1974) suggested the precipitation of iron from marine water because of upwelling of the bottom water into oxidizing environment.

Porosity reduction

The original porosity of the sandstone is reduced during the diagenetic process due to the process of compaction and cementation. Here, assumed the initial porosity for the Sillakkudi Sandstone to model the porosity evolution and relative role of cementation and compaction for porosity reduction. The Sillakkudi Sandstone are medium to fine grained, moderate to poorly sorted and have dominance of quartz (96%) in QFL framework composition which, qualifies to have an initial porosity of 45% (Atkins & Mcbride,1992). This is calculated by using the following formula and variation diagram of Lundegard (1992).

Compaction porosity loss (COPL): IP – [(100-Ip) X (MCP)}/ (100-MCP)]…. (1)
Cementation porosity loss (CEPL): IP – COPL X (T_c/MCP) ….. (2)

Where, COPL- Porosity Loss due to Compaction,
CEPL- Porosity Loss due to Cementation,
IP-Initial Porosity of sandstone (ie.45%),
T_c -Total volume of cement; 25%
MCP- Minus Cement Porosity (30%).

The relative values for COPL is 21.5 whereas CEPL is 27.

This infers that cementation was the major cause for the reduction in porosity and hence compaction is the secondary factor for porosity reduction. The process of early cementation may have reduced the porosity and established a stable framework of sand grains which has decreased the effect of compaction in later stages of diagenesis. Hence, the cementation enactment in the diagenesis, when compared to compaction in sandstone compared to compaction.

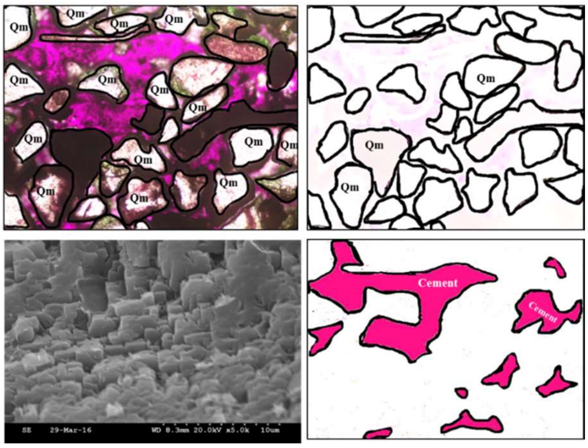


Fig 4. Calcite cementation in sandstone fabric

Discussion

Diagenetic features in Sillakkudi sandstone has different stages of compaction and cementation. The relative percentage of different petro-fabric contacts are free-floating, point, long, sutured and concavo-convex contacts. The relative high percentage of free-floating grains and point contact cemented by calcitic cement suggests that the sandstone were subjected to early cementation process and consequently little compaction effects. The relative high percentage of long contact advocates that the mechanical compaction was more dominant than the chemical compaction which is indicated by relative low percentage of sutured and concavo-convex contact. Two types of cement have been identified in the Sillakkudi sandstone; calcitic cement and ferruginous cement in which calcite is the dominating cement (90 %) than that of the ferruginous cement (10%) of the total cement in Sillakkudi sandstone. Calcite was the first cement precipitated in the pore spaces of sandstone, which is indicated by the free-floating grain (33%) and by the detrital grains showing point contact (46%) were cemented by calcitic cement and was replaced by the ferruginous cement which was precipitated in the later stages of diagenesis. Loss in porosity was due to early cementation process in comparison to compaction process. Hence compaction is the secondary process in porosity reduction. The detrital sandstone grains endured early cementation process, indicated by 33% of free-floating grains cemented by calcite. Calcite cementation is followed by compaction which is indicated by different type of petro-fabric contact in sandstone. Ferruginous cement is precipitated at the later stages of diagenesis which is due to dissolution of the ferromagnesian minerals and replacement of calcitic cement.

Conclusions

- Sillakkudi Sandstone is fine to medium grained arenaceous, sub-rounded-rounded, angular and moderate to poorly sorted and is classified as quartz arenite ($Q_{97.45\%}$ $F_{2.41\%}$ $L_{0.14\%}$)
- Monocrystalline quartz>Polycrystalline quartz, plagioclase feldspar are dominant. Biotite, opaque mineral and zircon forms the accessory mineralogy of Sillakkudi Sandstone.
- The modal composition of the Sillakkudi Sandstone reveals a continental block provenance where orogenic forces were absent and rapid erosion under hot and humid conditions which lead to dissolution of feldspar and lithic fragments.
- The relative percentage of free-floating grains (33%) and point contact (46%) cemented by calcite suggests that the sandstone were subjected to early cementation process, consequently petite compaction effects. The long contact (17%) suggests that the mechanical compaction was more dominant than the chemical compaction, indicated by relative low percentage of sutured and concavo-convex contacts.

- Calcitic cement (90%) and ferruginous cement (10%) were identified in the Sillakkudi Sandstone. Calcite was the first cement precipitated in the pore spaces of sandstone, which is deciphered by the 33% free-floating and 46% point contact grains were cemented by calcitic cement and was replaced by the ferruginous cement which was precipitated in the later stages of diagenesis.
- Loss in porosity was due to early cementation process in comparison to compaction process hence, the compaction is the secondary process in porosity reduction.

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