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Diagenesis and Pore Space Development of Datta Sandstones in Salt Range and Surghar Range

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ABSTRACT

Ten surface samples of sandstones of Datta Formation were collected from five different localities of Salt Range and Surghar Range and were petrographically analysed to examine the diagenetic changes and to evaluate the porosity development.

On the basis of the percentage of detrital minerals the sandstones have been classified as quartzarenites. Sedimentary structures of the sandstones indicate a subtidal environment of deposition. Cementation and decementation were found as the main diagenetic modification in the sandstones which have greatly influenced the porosity. Cementation by carbonates, silica and opaque iron oxides have almost entirely destroyed the primary porosity in some of the samples while dissolution of cementing material have created the secondary intergranular porosity during late diagenesis.

INTRODUCTION

The objectives of the study of the outcrop samples of the sandstone portion of the Datta Formation from Salt Range and Surghar Range were to examine the diagenetic changes and to evaluate these sandstone as potential clastic reservoir rocks.

A total of twelve samples were collected from five different localities (Figure 1) by a team of geologists of German Advisory Group and Hydrocarbon Development Institute of Pakistan (Ranke et al, 1987). In the Salt Range area three localities i.e. Khairabad, Nammal Gorge and a section, 3 km north of Kalabagh, and in the Surghar Range two localities, i.e. Chichali Pass and Baroch Nala were selected for the collection of sandstone samples of the Datta Formation.

Out of the twelve samples picked in the field, two were found to be arenaceous limestone during petrographic study. The present work is basically based on a portion of a previous study by Mergner et al (1989) with the reassessment of the petrographic results of the surface samples only.

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PETROGRAPHY OF INDIVIDUAL SECTIONS

Nammal Gorge Section

Nammal Gorge is located in the western portion of Salt Range (Figure 1), where rock sequence ranging in age from Permian to Paleogene is exposed. The complete sequence of the Datta Formation is approximately 200 m thick, constituting sandstone interclated with shale. Sandstone is white to light brown, medium to coarse grained, cross-bedded, laminated and partially bioturbated. Only one sample of the sandstone was collected from the middle portion of the formation.

Petrography

A concise summary of the petrographic study of the analyzed sample is mentioned in Table 1. On the basis of the percentage of the detrital grains the sandstone of the sample has been classified as quartzarenite (Pettijohn, 1986). Some important features of the petrographic analysis are given below.

Detrital Grains.— Detrital grains of the sandstone of Datta Formation exposed in the Nammal Gorge constitute fine to medium, subangular, well sorted, monocrystalline quartz, loosely cemented by diagenetic dolomites and opaque iron oxides. Detrital grains constitute about 62 percent of the total rock (Table 1).

Cement/Matrix Content.— Fine to medium grained dolomite crystals which constitute about 30 percent and opaque iron oxides (Figure 2) which constitute about 5 percent of the total rock were found as pore filling cement.

Mineralogical and Textural Maturity.— The rock is mineralogically mature as the detrital grains constitute almost entirely of stable quartz grains. Texturally also the sediment is mature as it contains no terrigenous argilaceous matrix and the grains are well sorted.

Diagenesis.— Loose cementation of the detrital grains by the late diagenetic dolomites is the most abvious diagenetic modification of the sandstone. Other diagentic features noticed in the rock are the rare quartz overgrowth,

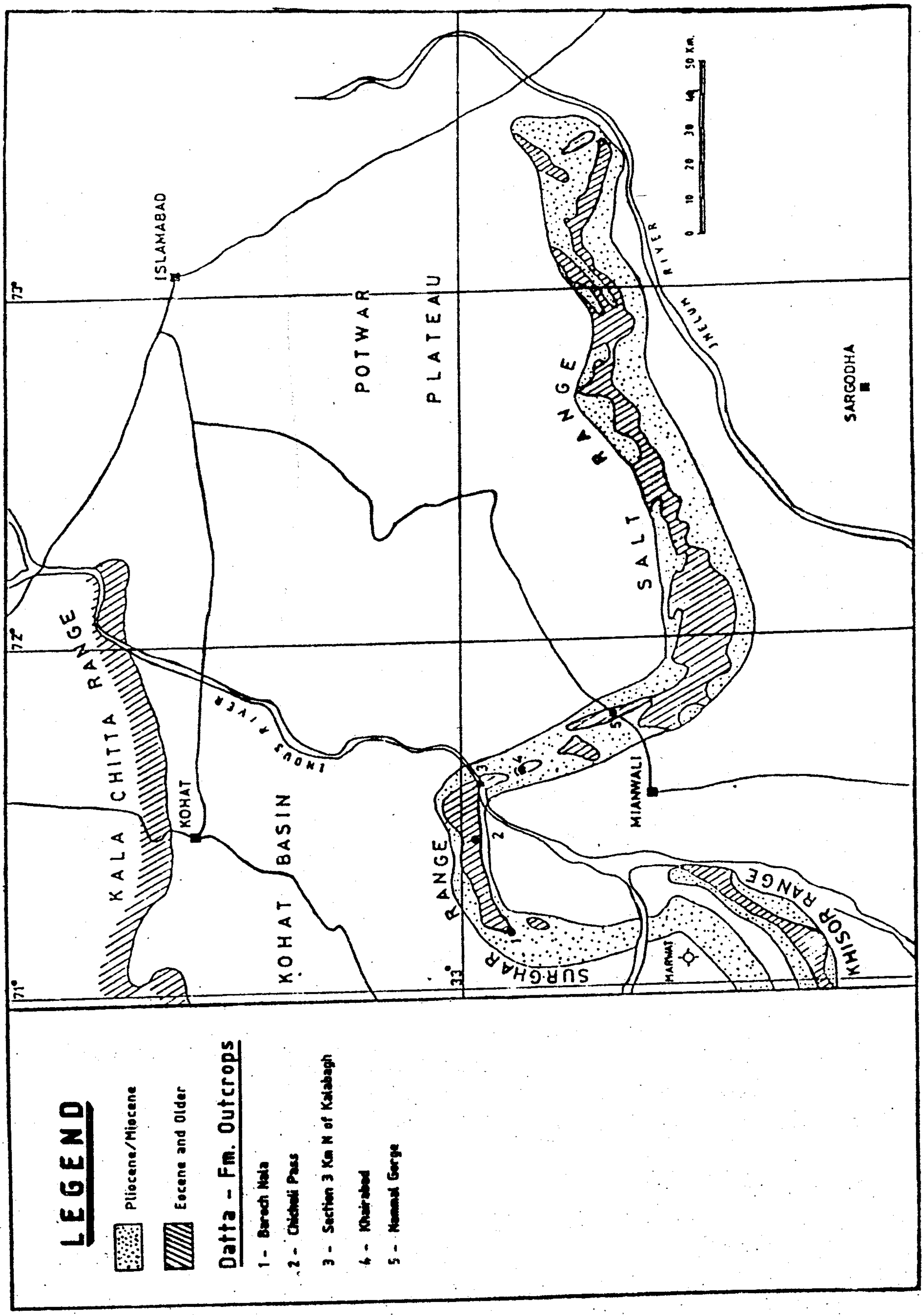

Figure 1.— Location of sampled outcrops of Datta Formation.

Table 1. Summary of petrographic analysis of Datta Sandstones.

Sample No. (Locality)	% of Detrital Grains			% of Cement			Grain Size	Grain Shape	Sorting	Porosity	
	Quartz	Feld-spar	Acce-ssory	Quartz	Carbo-nate	Iron Oxide				%	Type
SaR-421b (Nammal Gorge)	62	1	2	-	30	5	fine-medium	subangular	well sorted	5	intergranular reduced and enlarged, fabric selective leaching
SaR-420c (Khairabad) Gorge)	93	-	2	5	-	-	medium	subangular-subrounded	well sorted	35-40	intergranular reduced and enlarged, fabric selective leaching
SaR-420d (Khairabad)	96	-	2	-	-	2	fine-medium	subangular	well sorted	20	intergranular reduced and enlarged, fabric selective leaching
SaR-420e (Khairabad)	97	-	2	-	-	1	coarse	rounded-well rounded	moderately-well sorted	12	intergranular reduced and enlarged
SaR-418a (3 km N of Kalabagh)	93	-	3	3	-	1	fine	subangular	well sorted	35-40	intergranular enlarged
SaR-418b (3 km N of Kalabagh)	58	-	2	-	40	-	mediem	subangular-subrounded	moderately-well sorted	-	-
SgR-403a (Chichali Pass)	74	-	1	-	25	-	fine-medium	angular-subrounded	well sorted	2-5	vuggy
SgR-403b (Chichali Pass)	96	-	2	-	-	2	fine	subangular	well sorted	25-30	intergranular reduced and enlarged
SgR-406a (Baroch Nala)	63	-	2	-	-	35	medium-coarse	subangular-subrounded	moderately sorted	2.5	vuggy, intergranular reduced
SgR-406b (Baroch Nala)	95	-	1	2	-	2	fine	subangular-subrounded	moderately-well sorted	35	intergranular regular and reduced, fabric selective leaching

weak replacement of quartz grains by dolomite, late diagenetic filling of some of the pore spaces by iron oxides and finally selective leaching of potassium feldspar. Calcite cement was probably the first diagenetic precipitate which was subsequently replaced by dolomite during late diagenesis.

Porosity.— The original primary intergranular porosity is reduced during diagenesis by physical rearrangement of detrital grains through compaction and chemical precipitation of dolomite cement and iron oxides.

Khairabad Section

Khairabad section is situated in the western part of Salt Ragne (Figure 1) near the locality of Daud Khel, where the rock sequence ranges in age from Triassic to Pliocene. The sandstones of the formation are white, yellow and brown, fine to medium and coarse to very coarse grained. Three samples of the sandstone were collected from the middle portion of the formation.

Petrography

A brief summary of petrogrpahic study of the 3 analyzed samples is given in Table 1. These sandstones have been classified as quartzarenites on the basis of the percentage of the detrital minerals (Pettijohn, et al 1987). Some chereacteristic features of these three samples are discussed below.

Detrital Grains.— Detrital grains of all the three samples constitute almost entirely of quartz. The grains range in size from fine to coarse, and are mostly monocrystalline, with a few exceptions of polycrystalline grains, moderately to well sorted and subangular to subrounded. Inclusions are commonly noticed within the quartz grains in two samples (SaR-420c and SaR-420d).

Cement/Matrix Content.— Almost no cementing material or matrix content was found in the three samples except some localized minor silica cement in the form of quartz overgrowth (Figure 3) and clay mineral and iron oxides as pore fillings.

Mineralogical and Textural Maturity.— Mineralogically the sandstones of all three samples are mature as indicated by the detrital quartz grains. Texturally the samples are also mature as they are devoid of terrigenous argillaceous matrix and are well sorted.

Diagenesis.— The most prominent diagenetic feature of the sandstones of the three samples is the non-existence of cementing material or matrix content. The abundance of corroded quartz grains and secondary enlargement of some of the pores indicates the presence of some sort of precursor cement which was subsequently dissolved during late diagenesis. Other diagenetic features are rare to abundant quartz overgrowth, presence of authigenic kaolinite in one sample (SaR-420d) which was probably formed due to disintegration of feldspar grains, microfracturing in another sample (SaR-420e) due to compaction and presence of authigenic iron oxides as pore fillings. The common occurrence of secondary enlargement of pore spaces is probably due to quartz replacement by a former cement, which was later on removed due to leaching (Figure 4).

Porosity.— Porosity varies from 12% in sample SaR-420e to 40% in another sample SaR-420d, and is in the form of secondary intergranular. It looks that the existing porosity was developed in atleast two stages. The first stage of porosity development took place during early diagenesis when the unstable grains such as feldspar, were dissolved and the partial or complete replacement of quartz grains by the former cement, which could be carbonate took place. Later on, during late diagenesis, dissolution of the cement took place resulting in the development of secondary, enlarged porosity (Figure 5).

Section 3 Km North of Kalabagh

The section is located at the extreme western limit of the western Salt Range near the town of Kalabagh (Figure 1), where the exposed rock sequence ranges in age from Triassic to Miocene. The thickness of the Datta Formation in this section, has been reported as about 310m. The sandstones are white to red and medium-grained. Two samples of sandstones were collected from the middle part of the formation.

Petrography

A brief summary of the petrographic study of the two samples has been given in the Table 1. On the basis of the percentage of the detrital minerals the sandstones of the two samples have been classified as quartzarenites. Some of the salient features of the petrographic analysis are as follows:

Detrital Grains.— Sample SaR-418 constitutes almost entirely of detrital grains, which are fine to medium, sub-angular, well sorted and monocrystalline to polycrystalline. Detrital grains of sample SaR-418b are also almost entirely quartz and are medium, subangular to subrounded, moderately to well sorted and mainly

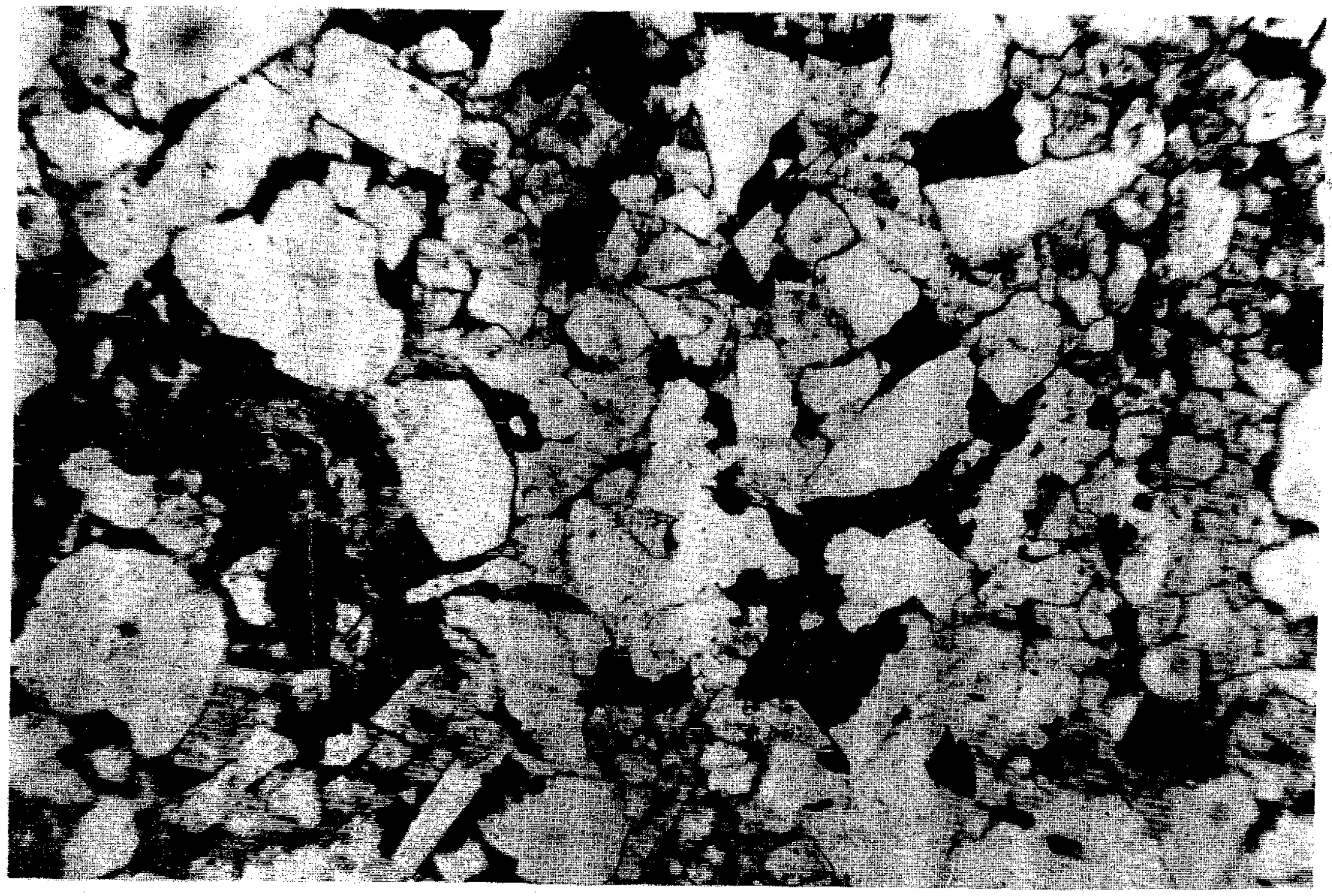

Figure 2.— Authigenic dolomites and iron oxides as pore fillings in a framework of detrital quartz grains (SaR-420b, ordinary light, x63).

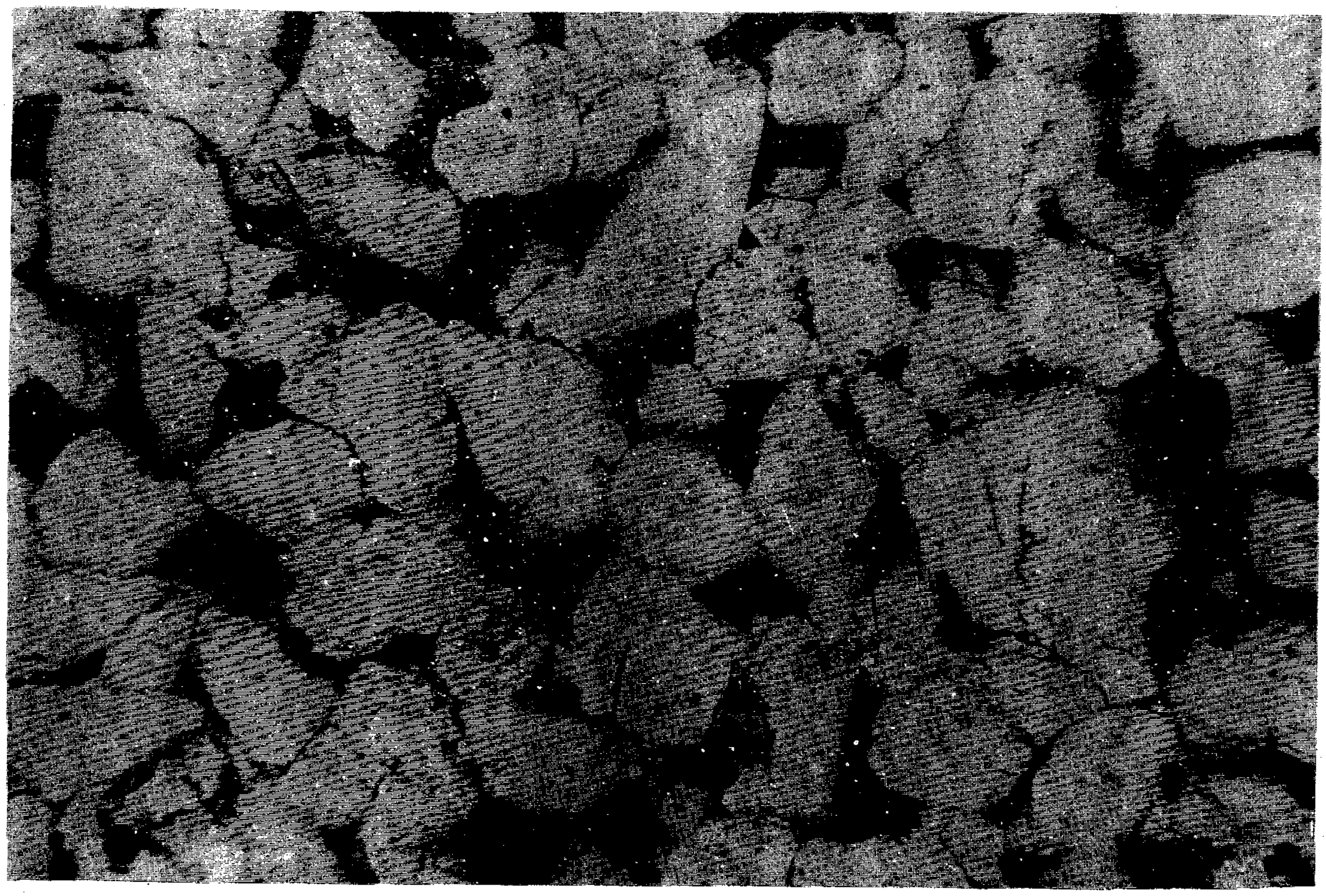

Figure 3.— Secondary enlargement of quartz grains in the form of euhedral crystal faces and development of secondary intergranular porosity (SaR-420c, ordinary light, x63).

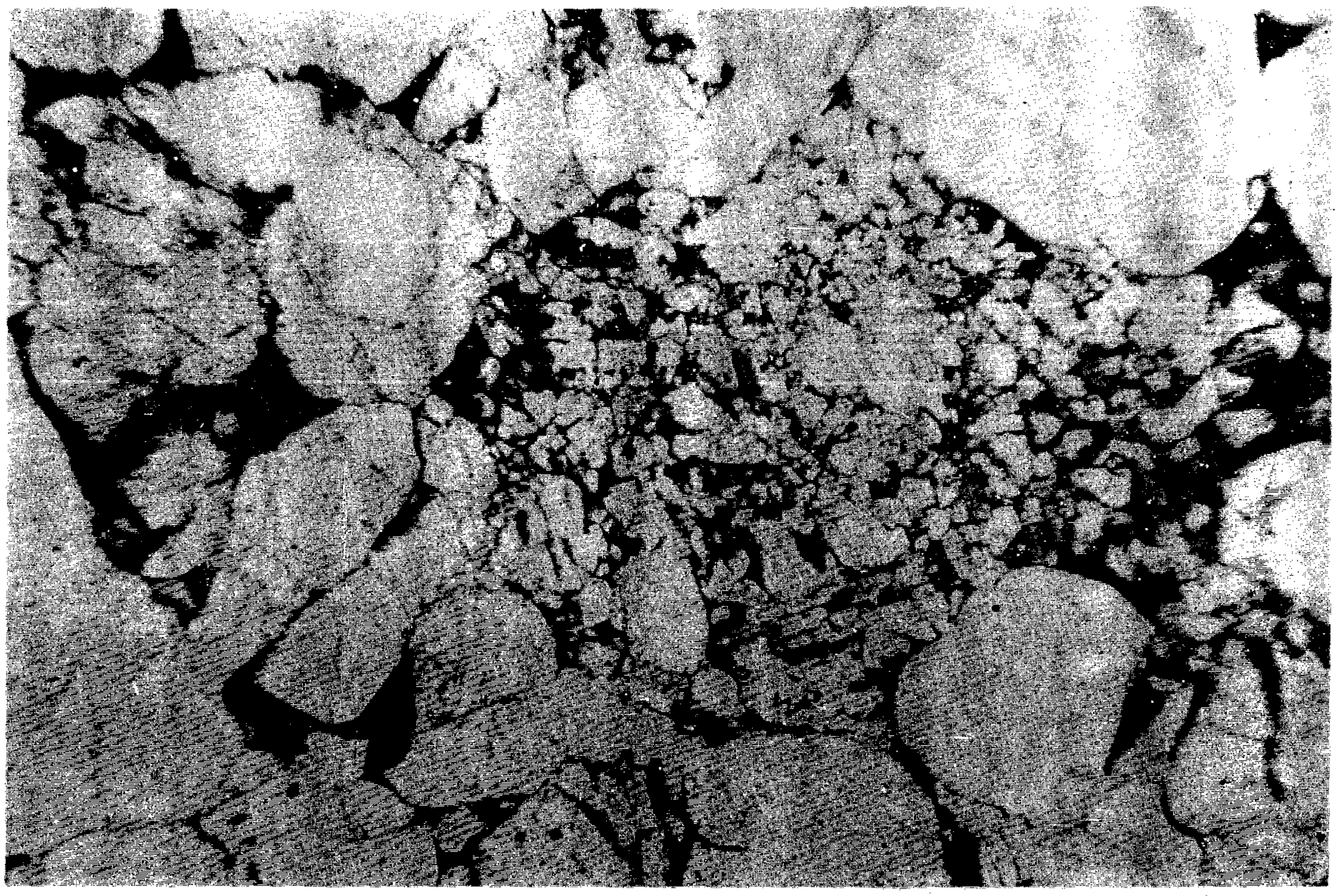

Figure 4.— Partial leaching of detrital grains and quartz overgrowth (SaR-420e, ordinary light, x25).

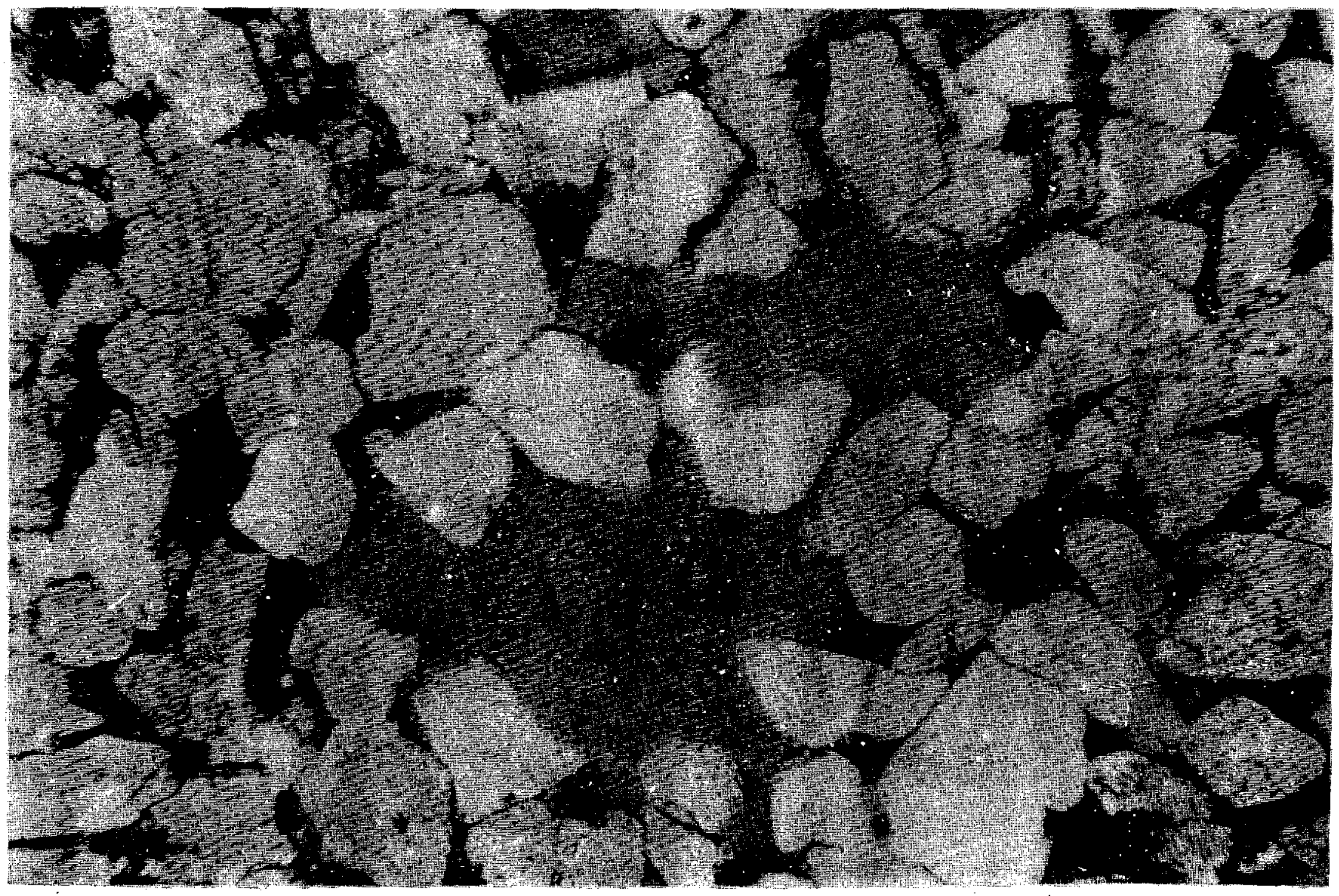

Figure 5.— Development of secondary vuggy porosity due to the leaching of detrital grains and precursor cement (SaR-420d, ordinary light, x63).

monocrystalline with a few polycrystalline forms. Detrital grains of sample SaR-418b constitute about 58% of the total rock.

Cement/Matrix Content.— Almost no cementing material or matrix content was found in sample SaR-418a except with some minor silica cement as quartz overgrowth and presence of some iron oxides in the form of pore fillings. In sample SaR-418b, however, calcite is present as cement (Figure 6) and constitutes about 40% of the total rock. Calcite cement is present generally in the form of large crystals, in which quartz grains are poikilitically enclosed giving the texture of floating grains. Clacite has also been seen filling the microfractures and forming inclusions within the quartz grains.

Mineralogical and Textural Maturity.— Mineralogically both the samples are mature as the detrital grains constitute almost entirely of quartz grains which are chemically most stable and physically resistant. Texturally sediments of both samples are also mature as no terrigenous clay matrix is present and the detrital grains are well sorted.

Diagenesis.— The prominent diagenetic features of sample SaR-420a are the quartz overgrowth, corroded grain surfaces, fractured grains and inhomogeneities in packing. Corroded grain surfaces and enlarged pore spaces indicate the presence of precursor cement, which was subsequently removed due to dissolution during late diagenesis. Marginal replacement of quartz grains by the former cement took place probably during early diagenesis. Important diagenetic feature of the sandstone of sample SaR-418b is the poikilitic calcite cement which indicates strong replacement of the quartz grains. Presence of calcite cement in the microfractures, developed within the quartz grains, indicate that pressure solution, due to compaction, took place before the cementation of the sediments by the calcite.

Porosity.— Visual porosity in sample SaR-418a has been estimated as 35% to 40%. Porosity type is intergranular enlarged which was produced due to dissolution of the former cement. The precursor cement not only occupied the pore spaces previously but marginally replaced the quartz grains too. Therefore, when dissolution of the former cement took place the secondary porosity, in the form of enlarged pore spaces, resulted. No porosity was found in sample SaR-418b due to uniform distribution of calcite cement, specially, under the situation when calcite cement is present in the form of large crystals in which quartz grains are poikilitically enclosed due to strong replacement of quartz grains by the cement.

Chichali Pass Section

Chichali pass is located in the eastern part of Surghar Range (Figure 1), where the exposed rock sequence ranges in age from Jurassic to Miocene. The exposed thickness of Datta Formation is approximately 120m, consisting of thick shale layers interclated with multicoloured sandstone beds of varying thickness. Sandstones are cross-bedded and commonly show indications of wave-action (flaser structures), bioturbation, channel fills and sole marks. Two samples were collected from the top portion of the formation with an interval of 10m.

Petrography

A brief summary of the petrographic study of the two samples has been given in Table 1. On the basis of the percentage of the detrital minerals the sandstones of the two samples have been classified as quartzarenites (Pettijohn et al, 1987). Some of the salient features of the petrographic analysis are as follows.

Detrital Grains.— Detrital grains of sample SgR-403a constitute about 74% of the bulk, and are composed entirely of quartz. Quartz grains are fine to medium grained, well sorted, angular to subangular and mainly monocrystalline. Sandstone of sample SgR- 403b constitutes quartz as detrital grains which is about 96% of the total constituents of the rock. Quartz grains are mainly fine grained, well sorted, angular to subangular and mostly monocrystalline. A few medium grained detrital quartz grains were also noticed.

Cement/Matrix Content.— In sample SgR-403a detrital quartz grains are embedded in a matrix of authigenic cryptocrystalline clacite. A few microcrystalline calcites were also noticed. In sample SgR-403b no cementing material or matrix was found except some minor irregular, isolated patches of opaque iron oxides occurring as pore fillings.

Mineralogical and Textural Maturity.— Mineralogically sediments of both the samples are mature as the detrital grains constitute entirely of quartz grains which are chemically most stable and physically resitant. Textrually also the sediments of both the samples are mature as they contain no terrigenous argillaceous matrix and the grains are well sorted.

Diagenesis.— The most obvious diagenetic feature noticed in sample SgR-403a is the presence of cryptocrystalline calcite as a pore filling. Other diagenetic features are the marginal replacement of quartz grins by carbonates and presence of microfractures within the

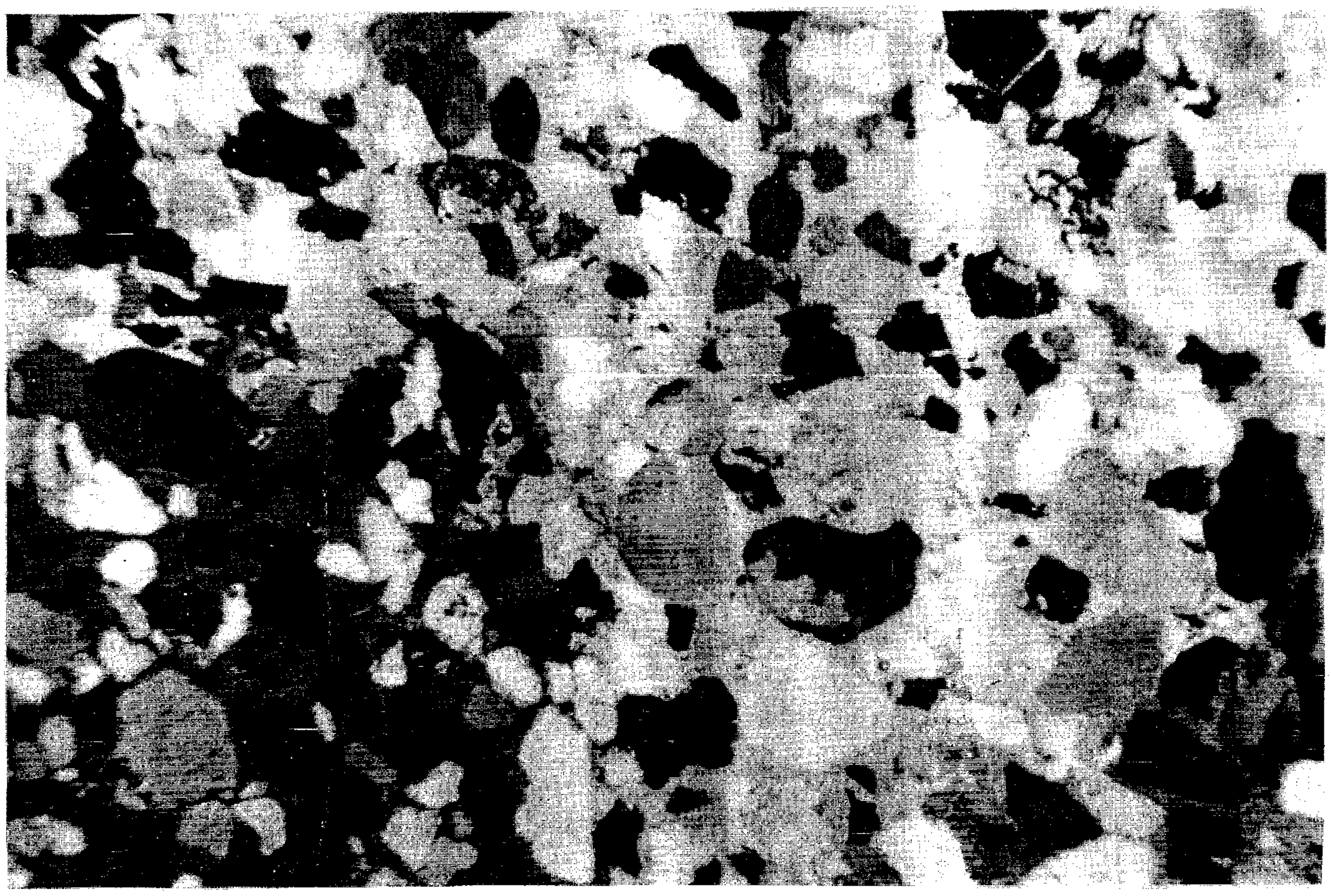

Figure 6.— Well cementation of the detrital quartz grains by carbonates causing the destruction of porosity (SaR- 418b, crossed nicols, x25).

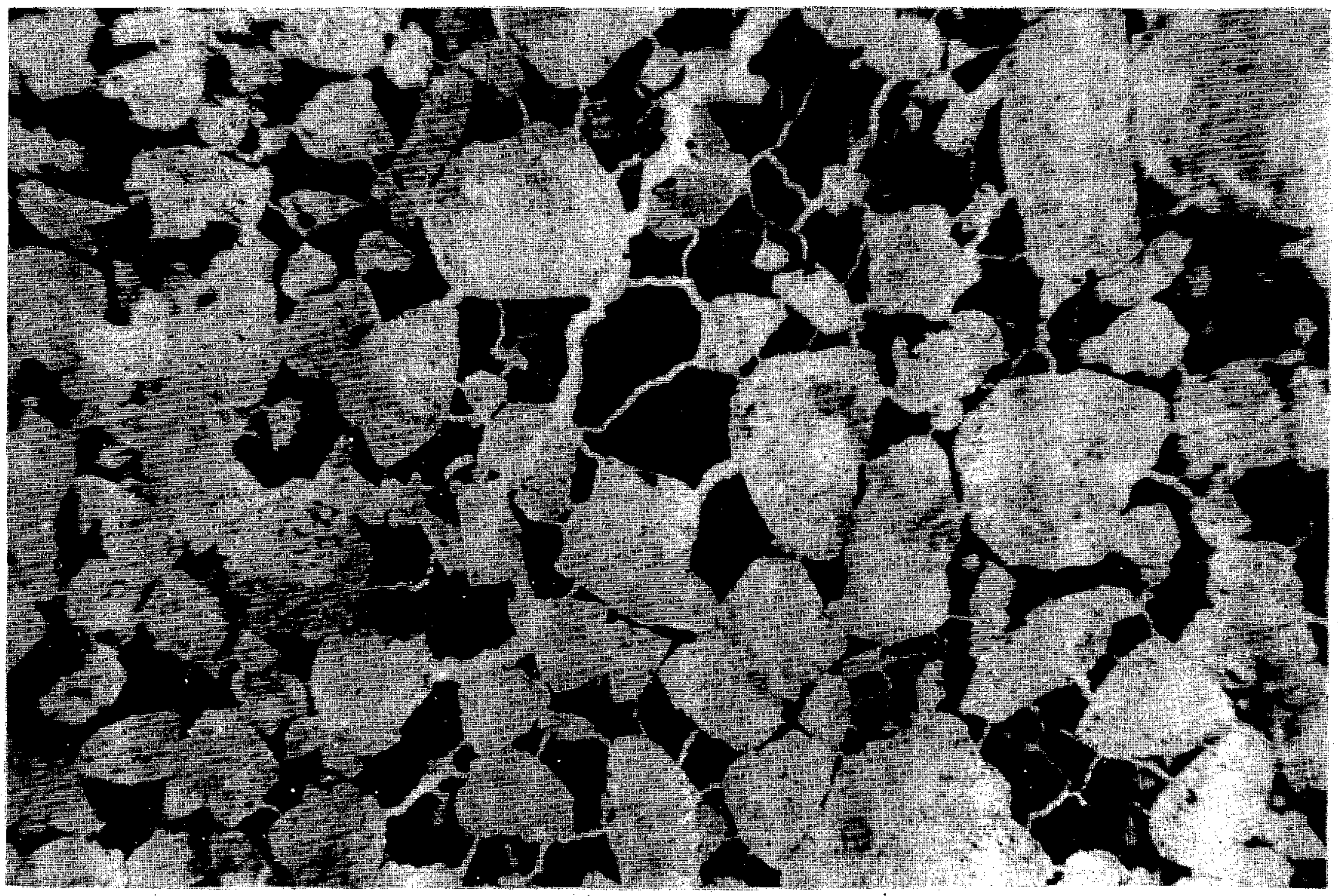

Figure 7.— Cementation of detrital quartz grains by opaque iron oxides (SgR-406a, ordinary light, x25).

quartz due to pressure solution. The presence of carbonate cement in the microfractures, developed within the quartz grains, indicates that pressure solution took place before the precipitation of carbonate in the form of cryptocrystalline calcite. In sample SgR-403b the prominent diagenetic feature is interpenetration and euhedral authigenic enlargement of detrital quartz grains. The high porosity and the enlargement of the pore-spaces indicate the presence of some sort of cement during early stage of diagenesis which was subsequently dissolved during late diagenesis. Small and localized patches of opaque iron oxides have been noticed as pore fillings.

Porosity.— In sample SgR-403a the primary intergranular porosity of the sandstone was almost completely destroyed due to authigenic precipitation of cryptocrystalline calcite, except some minor scattered vuggy porosity (2% to 5%). In sample SgR- 403b secondary intergranular porosity was formed during late diagenesis due to dissolution of early diagenetic authigenic cement.

Baroch Nala Section

Baroch Nala is located in the central part of the Surghar Range (Figure 1), where exposed rock sequence ranges in age from Jurassic to Pliocene. The exposed thickness of Datta Formation is approximately 50m, and its sandstones are yellow to brown, medium to coarse grained, thick bedded, cross-bedded, and bioturbated. Channel fills, worm tracks and flaser bedding are also present. Two samples were picked from the middle portion of the formation.

Petrography

A brief summary of the petrographic study of the two samples has been given in Tabel 1. On the basis of the percentage of the detrital minerals the samples have been classified as quartzarenites (Pettijohn, 1986). Some of the prominent features of the petrographic analysis are given below.

Detrital, Grains.— Detrital grains in sample No. SaR-406a constitute about 63% of the bulk and are composed of quartz. The grains are medium to coarse, subangular to subrounded and moderately sorted. Sandstone of sample SgR-406b constitutes quartz as detrital grains which is about 95% of the total constitutents. Quartz grains are medium to fine grained with a few larger ones, subangular to subrounded, moderately to well sorted and monocrystalline.

Cement/Matrix Content.— In sample SgR-406a authigenic opaque iron oxide, which constitutes about 35% of the total constitutents, is presnet as cementing material (Figure 7). Sediments of sample SgR-406b virtually have no cementing material or matrix except minor and very localized occurrence of opaque iron oxides as pore fillings.

Mineralogical and Textural Maturity.— Detrital grains of both the samples are mineralogically mature as they are composed entirely of quartz grains which are chemically most stable and physically resistant. Texturally the sediments of both the samples are also mature on the basis of the absence of terrigenous matrix and moderate to well sorting of the grains.

Diagenesis.— The most obvious diagenetic modification noticed in sample SgR-403a is the cementation of the sediments by authigenic opaque iron oxide. Other diagenetic features are some vugs filled by coarsely crystalline kaolinite, authigenic overgrowth of some of the quartz grains and microfracturing of some of the detrital grains due to compaction. In sample SgR-406b almost no cementing material or matrix was found except some minor localized irregular patches of opaque iron oxides as pore fillings. Presence of high value of secondary intergranular porosity, despite effects of pressure solution, indicates the occurrence of some sort of cement during early diagenesis which was subsequently removed due to decmentation during late diagenesis. Rare secondary enlargement of the detrital quartz grains due to authigenic overgrowth was also found.

Porosity.— In sample SgR-406a the porosity was severely reduced due to authigenic precipitation of iron oxides during diagenesis. High value of secondary intergranular porosity (visual estimates 35%) is however, developed due to dissolution of the precursor cement during late diagenesis.

DISCUSSION AND CONCLUSION

Environment of Deposition

Sandstones of all the ten outcrop samples of Datta Formation constitute entirely of quartz as the detrital grains. Feldspars, rock fragments and terrigenous argillaceous materials are missing; and therefore, on the basis of the presence of percentage of detrital quartz grains the sandstones have been classified as quartzarenites (Pettijohn et al, 1987). Detrital quartz grains, being chemically most stable and physically resistant, indicate an intensive recycling of the sediments. Well sorting of the grains and absence of terrigenous fine materials give a clue that the transporting medium was wind or wave dominated.

There is indication that, at the time of deposition, some of the detrital quartz grains were already secondary enlarged due to overgrowth. This phenomenon shows that the sediments of Datta Formation were derived from some pre-existing sandstones. Sedimentary structures, such as cross-bedding, flaser bedding, laminations, channel fills and partial to high biotrubation, indicate a subtidal environment of deposition.

Diagensis

The most obvious diagenetic modifications noticed in Datta sandstones are the cementation and decementation of the sediments. Carbonates, silica and opaque iron oxides are the main cementing materials. Carbonate cement is in the form of calcite and dolomite which are distributed uniformly and sometimes patchily as pore fillings, and occasionally as a replacement of detrital quartz grains. Calcite cement is also present in the form of large crystals in which quartz grains are poikilitically enclosed giving the texture of floating grains. This phenomenon indicates strong repalcement of quartz grains by the authigenic calcite cement.

Silica cementation mainly took place in the form of secondary enlargement of the detrital quartz grains by optically continuous overgrowths that resulted in the development of euhedral crystal faces as well as a mosaic of interlocking overgrowths. There are two possible sources of dissovled silica which resulted in the precipitation of cements; one could be the presence of inter shale beds, and the other was possibly the pressure solution due to high pressure developed at point contacts of the quartz grains.

The very common occurrence of microfractures within the detrital quartz grains, of some of the samples, is the evidence of burial diagenesis due to compaction. Some of microfractures have been noticed as filled by authigenic cement, indicating that cementation took place after compaction. It is difficult to explain the different stages of diagenesis, however, it looks that cementation took place during early diagenesis and decementation during later diagenesis. Dissolution of precursor cement resulted in the development of high value of secondary intergranular porosity.

Aspects of Pore Space Development

As we know that the study of pore space development of a reservoir rock is very important, because understanding and being able to predict the porosity trends is vital for oil and gas exploration as well as for reservoir engineering. Diagenesis has played an important role in the reduction and in the production of porosity in Datta sandstones exposed in the Salt Range and Surghar Range. In some of the samples compaction and cementation have almost completely destroyed the primary porosity (samples SaR-418b and SgR-406a), while in other samples decementation has created high values of secondary itnergranular porosity, sometimes as high as 40% (samples SaR-420c and SaR-418a). The mineralogically mature nature of these sandstones has played a role in the partial preservation of the primary porosity. At the same time secondary enlargement of the detrital quartz grains due to overgrowth, resulted in the partial reduction of the porosity. Secondary enlargement of the pore spaces, which resulted due to the marginal dissolution of the quartz grains, has also enhanced the secondary porosity.

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