THE APPLICATION OF FORMATION CORE ANALYSIS IN DESIGNING WELL STIMULATION TREATMENTS

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ABSTRACT

The design of successful well stimulation treatments requires a thorough knowledge of the geologic characteristics of the formations involved. A discussion of the current methods of analysis is presented. In particular, the application of X-ray diffraction, scanning electron microscopy and energy-dispersive X-ray fluorescence analysis is demonstrated. The relative strengths and limitations of all the methods of analysis currently in use are compared. Examples of actual analyses are given to illustrate the value of formation analysis to the design of stimulation treatments.

INTRODUCTION

The design of well stimulation treatments requires a thorough knowledge of the near-wellbore geology. The description of formation material is a process which involves many methods of analysis. The analytical techniques chosen are determined by the time allotted for the analysis and the type and detail of the information required. Reservoir description encompasses rock lithology, rock texture, depositional environments and diagenic history.

The quality of information generated by the analysis of formation samples is dependent on many factors. The variability of rock lithology often dictates that the sample size should be as large as can be practically handled. Sample quality can often be important, especially where degradation due to weathering, contamination or poor sampling technique is suspected.

Formation samples commonly analyzed include drill cuttings, sidewall cores and diamond cores. Diamond cores offer the most accurate stratigraphic placement and are not generally contaminated during the coring process. The broadest range of analyses can be conducted on diamond cores; although their high cost and the time consumed during the coring process often prohibits their use. Sidewall cores are less expensive, easier to obtain than diamond cores and offer good stratigraphic placement. The percussion method used in coring, however, often obscures rock texture, laminations and porosity. In addition, drilling mud wallcake may be present as a contaminant. Drill cuttings are the most economical formation sample obtainable, since they are a by-product of the coring process. Stratigraphic placement is uncertain due to the differences in rock densities and settling velocities. Contamination as a result of drilling mud invasion may be significant. Of the sample types available, drill cuttings can be subjected to the smallest number of analyses.

ANALYTICAL METHODS

X-ray Diffraction (XRD)

Technique

X-ray diffraction (XRD) is a technique commonly employed in the analysis of geologic samples. The impinging of X-rays on a powdered crystalline substance results in the diffraction of these rays from interplanar surfaces within the crystal lattice. The diffraction process results in a series of peaks produced at various angular positions as the sample is rotated through the X-ray beam. Combinations of peaks, their intensities and angular positions can be used to identify mineral species.

Applications

X-ray diffraction (XRD) is the primary analytical method used to identify mineral phases in geologic samples. In addition, XRD can be used to produce quantitative percentages. Due to inaccuracies inherent in the method, it is prudent to backup XRD results with another technique. By identifying and quantitating minerals present, XRD can be useful in lithologic description; i.e. whether a rock is a sandstone, limestone, shale, etc. The mineral content of a formation can seriously impact the type of fluid chosen. The presence of expandable clay minerals would suggest the need for clay stabilizers. Clay minerals such as kaolinite and illite may pose a fines migration problem when exposed to acid systems, dictating the use of fines suspending agents. The type of grain cement may determine whether acid-based fluids are to be considered. These and other mineralogic considerations are primarily delineated through the use of X-ray diffraction.

Scanning Electron Microscopy/Energy-Dispersive X-ray Fluorescence (SEM/EDS)

Technique

Scanning Electron Microscopy and the attendant use of dedicated energy-dispersive X-ray fluorescence instrumentation (EDS), has gained recent popularity for use in the study of geologic samples. The technique involves the impinging of an electron beam on a fragment of core material, which has been previously vacuum coated with a thin conductive layer of metal. Secondary electrons from the metal surface layer and X-rays from the minerals comprising the sample are produced. The secondary electrons are converted into a video signal which is displayed for viewing. The X-rays produced can be analyzed by the EDS to generate an elemental composition.

Applications

The primary use of SEM/EDS is in the description of formation material. Because of the three dimensional nature of the image produced, reservoir characteristics such as grain type, grain size, grain shape and grain sorting can be ascertained easily. Pore throat type, size and the extent to which pores are interconnected or primary porosity may be assisted by natural fractures is readily apparent. In addition, the type and placement of cementing or authigenic minerals is easily discernible. The quantification of mineral phases by XRD can be simplified by utilizing the SEM/EDS combination as a form of electron microprobe to obtain elemental percentages. Clay minerals and their sensitivity to fluid flow are of great concern to individuals involved in the design of well stimulation treatments. It is in the study of clay minerals that SEM/EDS analysis is finding its greatest usage. The identification of clay minerals present can be accomplished by observing crystal morphology and through EDS elemental analysis. Clay mineral growth as discrete clusters, grain coatings, pore linings or pore bridges can be observed easily. The type and extent of grain cement can be determined by an elemental analysis and can have a significant effect on the choice of acid-based stimulation fluids.

Thin Section Petrography

Technique

Thin section petrography is a traditional technique used by geologists to characterize reservoir rocks. Thin sections are prepared by mounting a small square of rock, previously cut with a rock saw, on a glass microscope slide with epoxy or canadian balsam. A thin sectioning grinder is then used to reduce the thickness of the rock until it is 30 microns. The slide is placed under a petrographic microscope and a high intensity light source is shown through the rock from beneath. Light passing through a thin slice of rock will be refracted by the various minerals present. When examined with two perpendicular polarizing filters in the path of the light source, a series of birefringence colors are produced. The colors are a diagnostic characteristic of each particular mineral. When the sample is rotated through 360 degrees, the birefringence colors will change.

Applications

The birefringence colors and their changes, when the sample is rotated, can be used to qualitatively identify mineral phases. In addition, the frequency of occurrence of particular minerals can be recorded in a technique called point counting. As a result, quantitative percentages can be generated which may be used to backup the results of X-ray diffraction (XRD) analysis. The primary application of thin section petrography is in reservoir description. Textural information such as grain type, grain size, grain shape and grain sorting is more easily obtained using thin sections than any other method. Because of the two dimensional view afforded the observer, porosity characteristics such as pore type, pore size or the presence of natural fractures can be more readily observed. Cementing minerals such as calcite, amorphous silica or clay minerals are more easily identified than with scanning electron microscopy (SEM). It is not possible, however, to differentiate between the types of clays as is the case with SEM. Trace minerals, which may not be present in quantities large enough to be detected by XRD, can be discerned through thin section analysis.

Wet Chemical Analysis

Technique

The reaction of core material to fluids can be utilized to assist in the choice of possible stimulation treatments. Wet chemical tests commonly performed in the laboratory include acid solubilities and fluid sensitivities. Acid solubility analysis involves exposing a known amount of powdered formation material to hot acid; usually HCl acid or a HCL/HF acid mixture. The amount of weight lost is expressed as a percentage. Fluid sensitivity analyses can take the form of immersion tests. Immersion studies entail the exposure of formation material chips, of known weight, to stimulation fluids at reservoir temperature. If the reservoir contains clay minerals which are sensitive to fluid influx, sloughing or fines generation may occur. The weight change is a relative measure of sensitivity.

Applications

Fluid sensitivity analyses are used primarily to determine the effect of various stimulation fluids on a formation. It is of primary concern to people involved in the design of stimulation treatments that the proposed fluid not be damaging. Cationic species released following fluid contact may prove bothersome if allowed to precipitate out of solution. Acids or other fluids used in these studies may be analyzed using inductively coupled plasma spectroscopy (ICP) to determine percentages. Calcium flouride ($Ca\ F_2$), Magnesium flouride ($Mg\ F_2$) and amorphous silica may be precipitated from HCl/HF acids. Iron hydroxides may precipitate from spent HCl acid systems. Knowledge of the presence of these cationic species allows designers of stimulation treatments to take precautionary measures in the form of the appropriate chelators. Fines generation or sloughing can be addressed by the addition of fines suspenders or clay stabilizers. Unfortunately, diamond cores are the only type of formation sample on which these tests can be performed.

Core Flow Studies

Successful well stimulation treatment design requires knowledge of the formation permeability; the ease with which fluid can flow through a rock. Laboratory measurement of permeability involves flowing a fluid under pressure through a cylinder of diamond core, in a longitudinal direction. If the formation produces primarily gas, the reference fluid can be nitrogen or air, if the reservoir produces mostly oil then a hydrocarbon such as diesel is usually chosen. As the testing proceeds, the amount of driving pressure required to initiate flow is recorded, as well as the volume of fluid throughput as a function of time. When the amount of fluid which is flowing through the output end has reached a constant rate, the test is stopped and all values are recorded. Using an equation derived from Darcy's Law, the permeability of the formation can be calculated. It is sometimes desirable to find out what effect the flow of a particular stimulation fluid will have on a core sample. Following the establishment of constant flow with a reference fluid as noted above, the chosen stimulation fluid is introduced in the opposite direction. When a state of constant flow is reached, the permeability can once again be calculated. The change in formation permeability from one fluid to the other is known as the regained or lost permeability.

Applications

Core flow studies allow the direct measurement of formation permeability. In addition, the change in permeability with the introduction of stimulation fluids can be observed. Following the permeability determinations, an SEM/EDS study can be undertaken to document any effects on framework minerals, such as differential etching of carbonates or gross collapse of sandstones after the removal of grain cements by acids. The migration of clay minerals as fines or sloughing due to clay swelling can be also noted. It is obvious from the discussion above that flow studies can only be performed on diamond cores.

Rock Mechanics

Technique

The properties of rock strength are needed to determine the minimum amount of force which must be exerted at the perforations of a well to initiate a fracture during fracture stimulation. A sidewall core, taken horizontally from a full diameter core, is needed to determine a reservoir's strength. The core plug is mounted in a hydraulic press and pressure is slowly applied until failure occurs. A plot of increasing applied stress versus strain is plotted.

Applications

Rock or matrix strength is used to determine Poisson's Ratio and Youngs's Modulus. These parameters along with the natural formation pressure due to trapped gases and fluids and the axial stress or overburden, are used to calculate the minimum compressive stress which will cause formation parting. It is the compressive stress which is needed to decide what viscosity fracturing fluid will be chosen and at what rate it will be pumped.

CONCLUSION

Stimulation of oilwells requires a background in those properties of the reservoir in question that can most affect the design parameters. Thorough knowledge of the formation geology ensures that the stimulation fluid will be non-damaging and that well production increases will be maximized. In addition, if the mineralogic considerations are well documented, then unnecessary fluid components can be deleted and cost reductions can be realized.

CORE ANALYSIS PROCEDURES AND INFORMATION GENERATED

	XRD	SEM/EDS	Thin Section	Wet Chem.	Core Flow	Rock Mech.
Qualitative Mineralogy	1	2	1			
Quantitative Mineralogy	1	2	1	3		
Lithology	2	1	1			
Grain Size		1	1			
Grain Shape		1	1			
Grain Sorting		2	1			
Grain Type		1	1			
Pore Type		1	1			
Pore Size		1	1			
Porosity Quality		1	2		1	
Fractures		1	1			
Cement Type		1	1			
Authigenic Minerals		1	1			
Deformation		2	1			
Diagenic History		2	1			
Depositional Environments		2	1			
Clay Mineralogy	1	1	3			
Trace Minerals	3	2	1			
Acid Solubility				1	1	
Fluid Sensitivity	3	3	3	1	1	
Fines Migration	3	3	3	1	1	
Cationic Precipitation				1	2	
Poisson's Ratio						1
Young's Modulus						1

Key
1 - Primary Method
2 - Secondary Method
3 - Possible with Backup

REFERENCES

1. Neasham, J. W.: "Applications of Scanning Electron Microscopy to the Characterization of Hydrocarbon-Bearing Rocks", Scanning Electron Microscopy, Vol. 1, 1977.
2. Pittman, E. D. and Thomas, J. B.: "Some Applications of Scanning Electron Microscopy to the Study of Reservoir Rock", SPE 7550, 1978.
3. Neasham, J. W.: "The Morphology of Dispersed Clay in Sandstone Reservoirs and its Effect on Sandstone Shaliness, Pore Space, and Fluid Flow Properties", SPE 6858, 1977.
4. Dennis, M. J.: "The Application of Core Analysis to Well Treatment Design", Strawn and Canyon Sands Short Course, Abilene Christian University, Abilene, Texas, 1983.

Figures 1-8 are the results of X-ray diffraction and scanning electron microscopic analysis of formation material belonging to the Strawn Group.

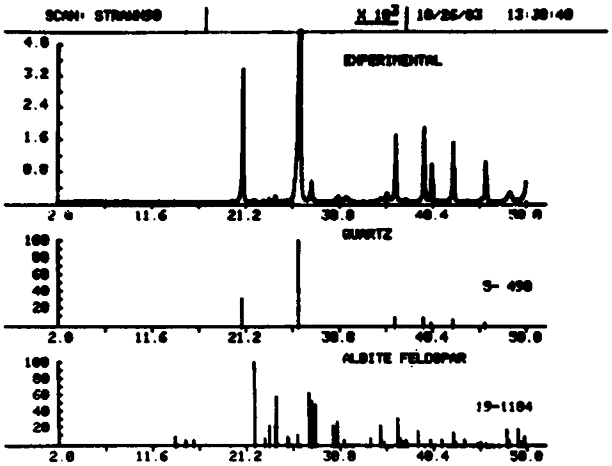

FIGURE 1. X-ray diffraction pattern of the Strawn formation material, 4,898 foot section, compared to J.C.P.D.S. standard patterns for quartz and albite

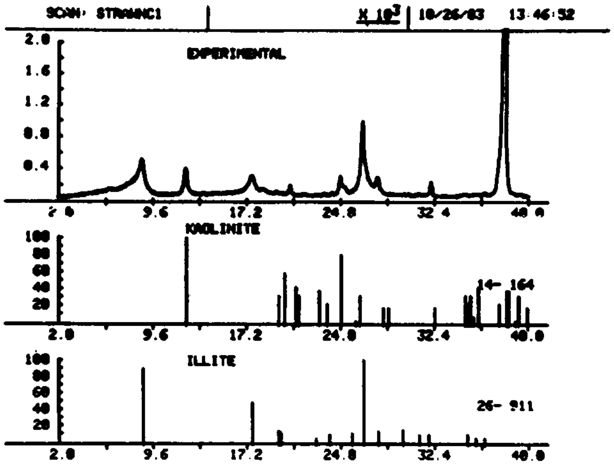

FIGURE 2. X-ray diffraction pattern of the clay-sized fraction of the Strawn material, 4,898 foot section, compared to J.C.P.D.S. standard patterns for kaolinite and illite clay minerals

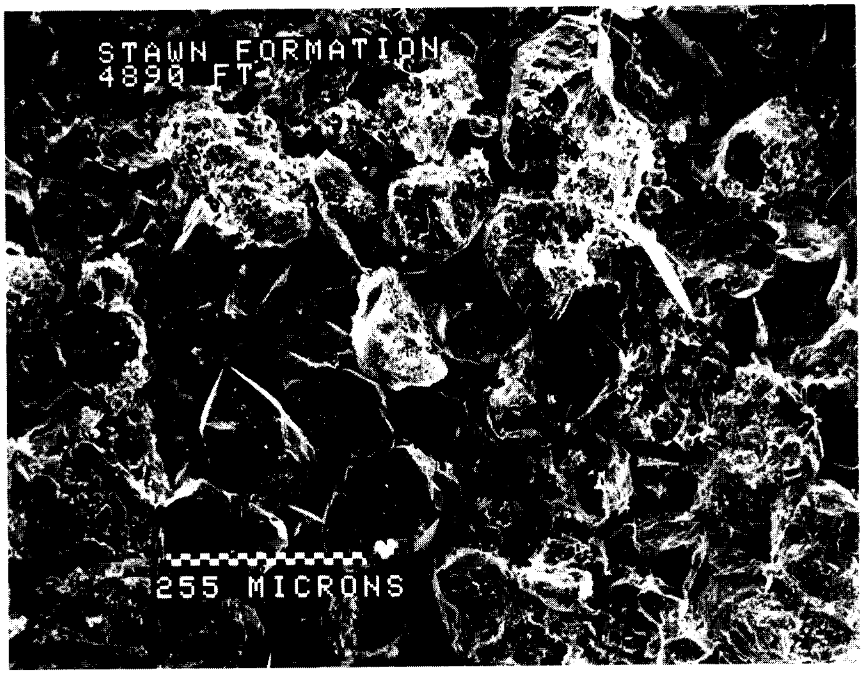

Figure 3 - Scanning electron micrograph of the 4890 foot interval, Strawn Group. The micrograph above shows a fine-grained well-sorted framework of quartz grains cemented by clay minerals. Authigenic regrowth of quartz is readily apparent. Magnified 100 times.

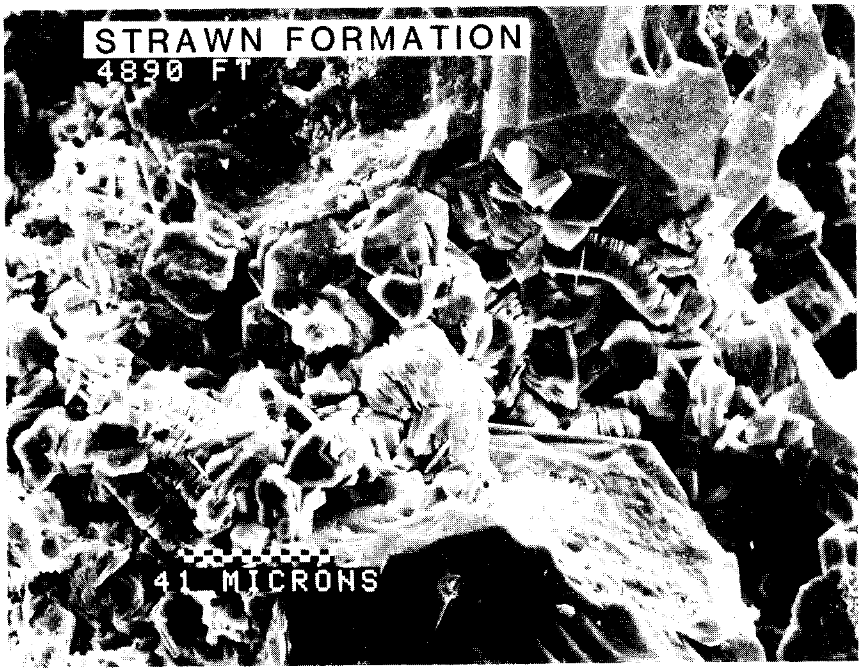

Figure 4 - Electron micrograph of an enlarged portion of Figure 3. The large, well-formed crystal faces of quartz grains (Q) suggests that an authogenic regrowth of quartz has taken place. Authigenic kaolinite clay can be seen bridging the intergranular void between quartz grains. Magnified 490 times.

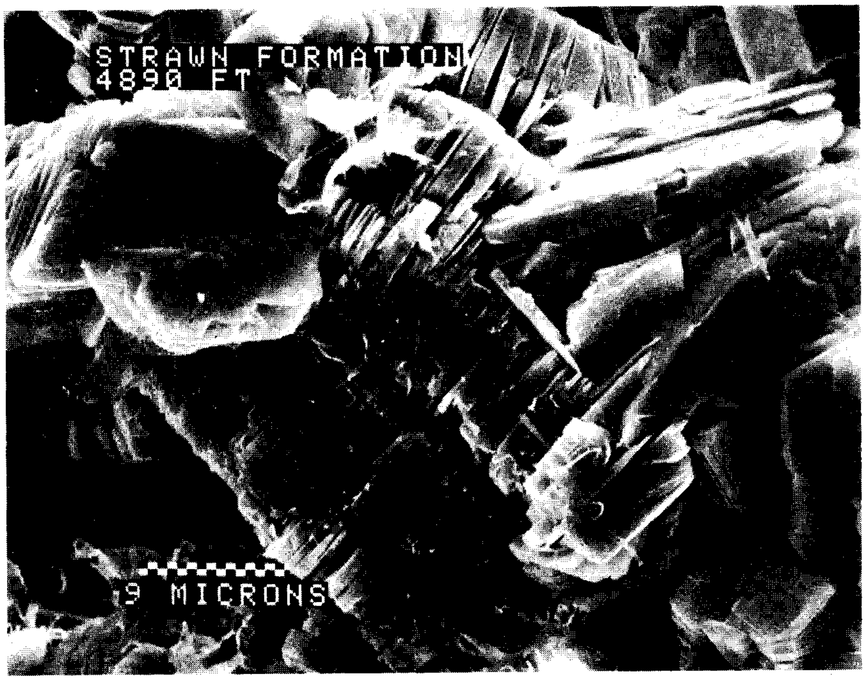

Figure 5 - Electron micrograph of an enlarged section of Figure 4. The distinctive morphology of kaolinite can be easily discerned. Magnified 2200 times.

Figure 6 - Scanning electron micrograph of an isolated aggregate of illitic clay. Note the distinctive filamentous appearance. Magnified 2500 times.

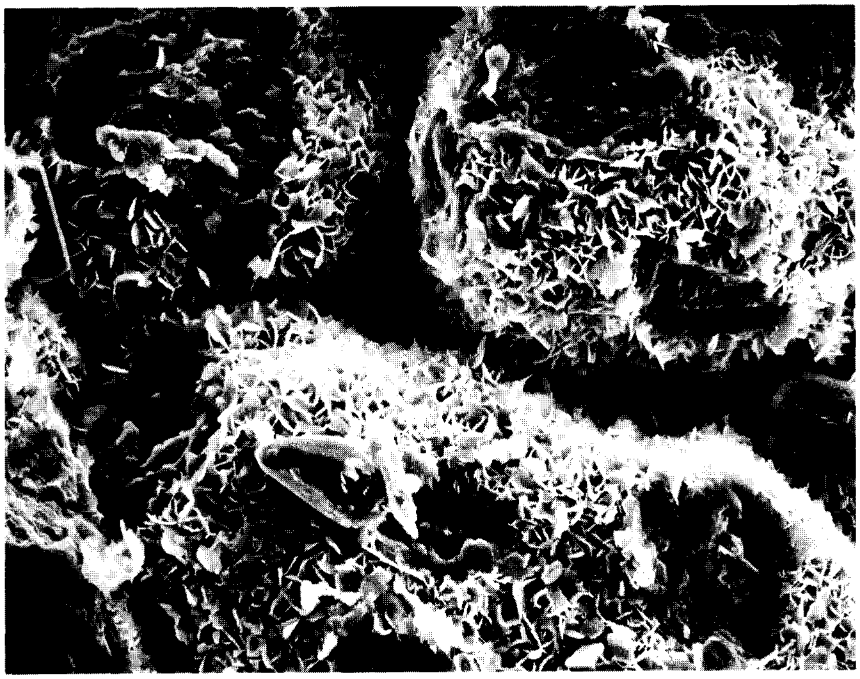

Figure 7 - Electron micrograph of chlorite clay coating quartz grains and lining pore spaces. Note the blade-like crystal morphology. Magnified 1200 times.

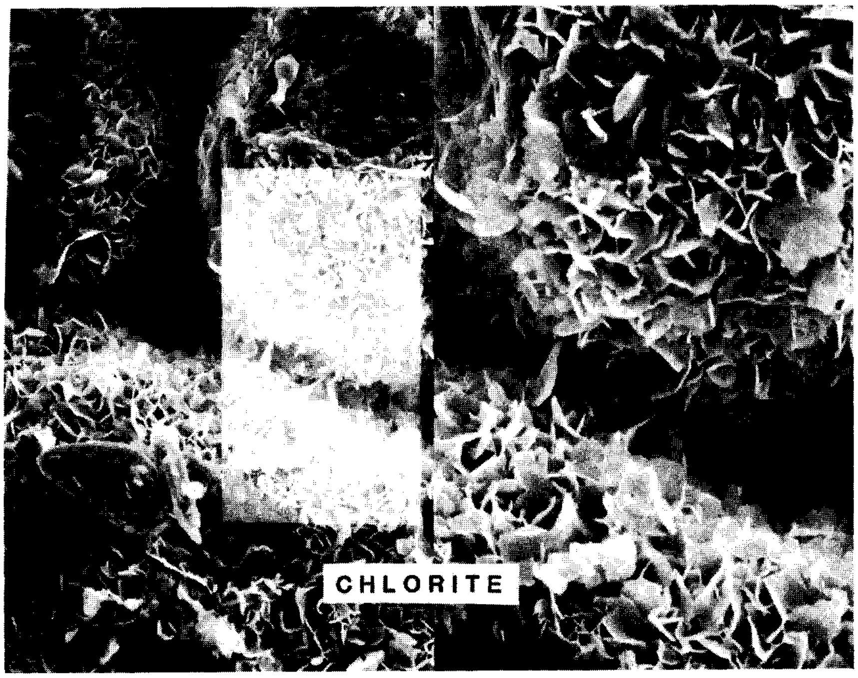

Figure 8 - Electron micrograph of chlorite clay coating quartz grains and lining pore spaces. Note the blade-like crystal morphology. Magnified 1200 times.