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SCALE SAMPLES FROM THE JUNE 1988 WELL TEST
AT THE SALTON SEA SCIENTIFIC DRILLING PROJECT
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Scale Samples from the June 1988 Well Test at the Salton Sea Scientific Drilling Project

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Abstract

Chemical analyses for major and minor elements were run on seventeen scale samples collected from the line and pond of the State 2-14 geothermal well. X-ray diffraction and detailed scanning electron microscope analyses were run on five selected samples from the seventeen.

Scale taken from the lines was high in amorphous material containing primarily Fe and Si oxides. There were also crystalline phases with significant amounts of Na, Cl, K, Ca, S, Cu, Ag, Pb, and Zn. The pond scale samples were high in NaCl, with significant amounts of Fe, Si, Sr, Cu, Pb, Zn, Cd, As, Sb, and Li.

The SEM analyses show that: both the amorphous Fe-, O- and Si-bearing scale and halite are nearly ubiquitous, and that the composition of the amorphous phase varies; barite is common; magnetite precipitates at the high-temperature end of the line; sulfides appear throughout the piping, with zinc and lead sulfides predominating at the hotter end and silver sulfide towards the cooler end; and the chlorides of potassium and silver are present as well as halite. Textures and crystal form are illustrated by typical micrographs.

In general, the scale in the lines and pond consists of a large number of different crystalline phases and an amorphous phase of varying chemical composition; these phases change significantly with run conditions.

Introduction

A research borehole, the State 2-14 well, was drilled to a depth of 3.22 km in the Salton Sea geothermal system of southern California. The drilling was part of the Salton Sea Scientific Drilling Project of the U. S. Continental Scientific Drilling Program and was completed in March 1986. The borehole encountered temperatures of up to 355°C and produced metal-rich, alkali chloride brines containing 25 wt% of total dissolved solids (Elders and Sass, 1988¹).

A 19-day step-rate flow test of the State 2-14 well was run from June 1 to June 20, 1988 by Mesquite Group, Inc.², for the prime contractor on the well, Bechtel National, Inc.³. After the flow test, 17 scale samples were taken from the system as shown in Figure 1 and as described in Table 1. This report includes the chemistry of all 17 and more detailed analyses of five selected samples.

Chemical analyses and X-ray Diffraction Analyses

¹Elders, W. E., and John H. Sass, 1988, The Salton Sea Scientific Drilling Project: Jour. Geophys. Res., v. 93, No. B11, p. 12,953-12,968

²Mesquite Group, Inc., 221 N. Harbor Blvd., Fullerton, CA 92632

³Bechtel National, Inc., 50 Beale St., San Francisco, CA 94105

Splits were made of the 17 samples in accordance with instructions from the University of Utah Research Institute (UURI) x-ray diffraction and chemistry laboratories. UURI provided chemical analyses and x-ray diffractograms.

Tables 2 and 3 give the bulk chemical analyses for major and minor elements respectively. A "C" was appended to the sample numbers to indicate the part of the sample taken for chemical analysis. On the basis of the chemistry and the sampling locations, five representative samples were selected for more detailed analysis. Table 4 gives the mineral phases identified by x-ray diffraction.

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Scanning Electron Microscope Analyses

Representative pieces of the 5 selected samples were examined using a scanning electron microscope (SEM) with energy dispersive spectroscopy capabilities. Descriptions of the observations follow. An "S" was appended to the sample numbers to indicate the part of the sample taken for SEM analysis.

Sample 2S

Sample 2S is salt scale taken from loose crust on the bottom of a pipe at the downstream HP isolation valve. In hand sample it is very dark with a thin dark-reddish tarnish or coating on at least one its two surfaces; the second surface, when not tarnished, is crystalline and light brown in color.

Sample 2S was analyzed in the SEM (using standardless ZAF corrections) in cross-section with the SEM. A BSE image (photo 1) of the face to be analyzed revealed mineralogical and textural zones within the sample. Four zones were defined prior to analysis on the basis of these mineralogical and textural differences. In photo 1, zone A is the top thin layer (probably next to the pipe) of amorphous-looking material. Zone B, beginning immediately below zone A, is the area with the highly reflective material. The layered-looking area below zone B is zone C. This zone contains no reflective material. Zone D is the bottom thin, darker layer. It contains relatively large, cubic crystals and an occasional mineral of high reflectivity.

A high-magnification BSE image of zone A (photo 2) shows a darker (i.e., less dense) area sandwiched between two lighter (denser) areas. An EDS analysis of a lighter and a darker area (spots 6 and 7 in photo 2) reveal that the difference in shades is due mostly to Si content; the darker area contains measurably more Si by weight. Both areas are characterized by the elements O, Fe, Cl, Si, and Ca.

Photo 3 is a high magnification BSE image of zone B. From this photo, the non-crystalline "matrix" and two minerals of different reflectance can be discerned (labelled 8, 9, and 10, respectively). An EDS analysis of the matrix of zone B (spot 8) shows peaks of Fe, O, and Cl with a trace of Si and Ca. The quantity by weight of Fe is considerably greater in this area than in zone A. An EDS analysis of spot 9 yields Pb(S) with some Cl and K--another galena. Some of the Cl and K is probably picked up from the matrix, not the galena. A high magnification BSE image of spot 9 (photo 4, the more highly reflective mineral) shows the galena is in cubo-octahedral form with some dissolution evident. The galena throughout sample 2S occurs with halite and/or sylvite. An EDS analysis of spot 10 gives Fe, Zn, and S with a trace of Cu. A high magnification image of spot 10 (photo 4, dark mineral to the right of the galena)

shows this mineral occurs as poorly-developed crystals. Both EDS and XRD (SAR) analysis of this mineral suggests that it is sphalerite.

Zone C is characterized by small spheres encased in an "gel-like" coating (SAR) (photos 5 and 6). An EDS analysis of these spheres shows some of them to be almost exclusively Fe and O, and others to have the same chemistry as the matrix material. A high magnification SE image of one of the Fe₂O₃ spheres (lower sphere in photo 6) reveals that they are poorly formed octahedral-looking crystals. Based on SEM and XRD data, these crystallites are believed to be magnetite.

Zone D consists predominantly of large, well-developed halite crystals (photo 7) with an occasional galena crystallite among the halite.

Assuming that the top surface of this sample is the pipe surface as its curvature suggests, then the layers were deposited in the order A, B, C, D. The layer of exclusively amorphous material consisting of Fe, Cl, Si, Ca, and O, then, formed first, followed by the galena- and sphalerite-rich zone, the magnetite-rich zone, and finally the halite-rich layer.

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Sample 7BS

Sample 7BS is taken from a control valve, run A, on the north pipe downstream. In hand sample it is dark and vitreous with a very thin, brown coating on one side and a thick porous-looking yellow-brown coating on the other. The yellow-brown surface is convex and, therefore, may be the pipe surface.

7BS was analyzed in cross-section with the SEM, and polaroid photographs of BSE and SE images were taken. In the BSE image of photo 8, the yellow-brown coated convex pipe(?) surface is facing up (top of the photograph) and the brown, thinly coated solution(?) surface is facing down. The sample is divided into four zones: A, B, C, and D. Zone A is the topmost, very porous-looking layer that lacks any highly reflective material. Zone B begins just below A and consists of highly reflective material and large, elongate areas (comprising about 50% of this zone) of dark, porous-looking material. Zone C begins where the dark, elongate areas pinch out. This zone also contains material of high reflectivity and dark pockets, but both are significantly less here. Zone D begins where the last of the dark, porous pockets ends. In this zone, the "matrix" material is dense and contains a very thin, concentrated layer of a highly reflective mineral.

Zone A contains lighter and darker areas. A high magnification BSE image of this zone (photo 9) reveals that the shade differences are due to the porousness of the material. The light areas are a dense, gel-like material while the dark areas consist of mostly void space. An EDS spectrum of both areas yields the same analysis: Fe, O, Si, and a trace of Mn.

In zone B, the "matrix" material has the same EDS spectrum as zone A with the same relationship of porous and dense to light and dark matrix. High magnification BSE images of the bright mineral (photo 10) reveal small (~10 mm in length) needle-like clusters. Typical EDS analysis of these clusters yields Ba, S, O, Sr, and a trace of Ca and Fe. The crystal form and EDS spectrum identify this mineral as Sr-bearing barite.

A zone C analysis was skipped due to time restrictions. A quick look at this area, however, suggests that it has basically the same mineralogy as zone B.

Zone D has an entirely different appearance than zones A, B, and C. High magnification BSE images of the bright layer in this zone reveal a variety

of crystal forms (e.g., photos 11 and 12). [An SE image of this material (photo 13) was also taken.] Photo 11 shows a bright, microgranular mineral in a dense, amorphous-looking matrix. The matrix in the immediate vicinity of this material is of a lighter gray than the rest of the zone. An EDS analysis of this mineral yields Cu, Fe, S, Si (from the matrix), and a trace of Ag and Cl. The crystal form and EDS spectrum suggest that this mineral is chalcopyrite. An EDS spectrum of the lighter "matrix" immediately surrounding the chalcopyrite yields Fe, O, Si, minor Ag, Cu, Cl, and a trace Ca and Mn. The only apparent difference between this area and the dark "matrix" in element constituents is the minor Ag, Cu, and Cl.

Photo 12 shows two more crystal forms found in this area: rosettes and botryoidal masses. An EDS analysis of the rosette yields Cu, S, O, minor Fe, Si, and a trace of S. The crystal form suggest that this is an Fe-bearing covellite. The botryoidal masses around this rosette give about the same spectrum.

The crystallization history of this sample is vague at best. Assuming that the top, porous surface is the pipe surface, as its curvature suggests, the porousness decreases toward the solution surface, and by the time zone D is reached, the matrix material is dense. The porous matrix could be an effect of either dissolution or growth of the scale. Barite is the only apparent crystalline phase in the porous zones, and there is no way to determine when, relative to the matrix, it crystallized. The chalcopyrite/covellite layer of zone D appears to have formed separately from the rest of the layers.

Sample 8CS

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Sample 8CS is salt scale taken from a control valve, run B, on an upstream gasket. In hand sample it is dark and vitreous. The pipe(?) surface is flat and tarnished light-brown. On a few small pieces this surface is corrugated. The solution(?) surface has a rusty coating, but on most of the large pieces this is in turn covered by a light-brown tarnish. The pipe-facing edges of the sample have rims.

8CS was analyzed in cross-section with the SEM, and polaroid photographs of BSE and SE images were taken. In photographs what is most likely the solution surface is facing up (toward the top of the photographs) and the pipe surface down. Based on both mineralogical and textural differences, 8CS was divided into three zones: A, B, and C; lettered in the order in which each zone was analyzed. Zones A, B, and C can best be discerned in the BSE image of photo 14. Zone A is the topmost layer and contains highly reflective material. This undulating layer can be traced on both edges in photo 14, and sets back from the rest of the face analyzed. Zone B is the bottommost, thin layer and it also contains a highly reflective material. It too can be traced across both faces. [The face least oblique (the left face) to the photograph was the one analyzed.] Zone C is the intermediate zone.

Zone A, which bounds the solution(?) surface, is shown in consecutively higher magnification BSE images in photos 15 and 16. Apparent in photo 16 are cubic crystals with dissolution textures (hollowed centers) at the top edge of the zone; a botryoidal, highly reflective mineral in the upper left corner; and highly reflective, compact masses through most of the photograph.

A high magnification SE image (photo 17) of the botryoidal mineral also reveals a cubic-looking mineral associated with it. An EDS analysis of the botryoidal material yields Cu and S with a trace Ag, i.e., covellite. An element analysis of the cubic mineral yields Ag and Cl with traces of Na, Fe, Cu, Si; i.e., chlorargyrite. An EDS analysis of the amorphous, dense matrix material of

photo 17 yields O, Si, Fe and traces of several other elements. An EDS spectrum of the compact masses reveals that it is a Cu,Fe sulfide, but the crystal form is too nondescript to identify the mineral--it could be Fe-poor chalcopyrite, Fe-bearing covellite, or perhaps even bornite (Cu_5FeS_4) (photos 18 and 19). The BSE image of photo 19 beautifully illustrates the intergrowth of chlorargyrite (cubic with the highest reflectivity) and halite (large cubic crystals with the lowest reflectivity) in the upper center and far left of the photo. A very high magnification SE image of the "matrix" in this zone (photo 20) reveals the presence of many ~0.2 mm diameter particles. A quick EDS spectrum of one of these particles yields the same spectrum as the matrix.

Zone B, the bottom layer bounding the pipe surface, is shown in consecutively higher magnification BSE images in photos 21 and 22. This zone is characterized by tabular to stubby crystals of varying sizes (all < 10 μm in length) having high reflectivity in a dense, amorphous "matrix." An EDS analysis of several of these crystals yields Ba, S, O, and minor Zn. The crystal form and EDS spectra identify this mineral as Zn-bearing barite (the tabular shape is a more common crystal form for barite than the needle clusters found in the previous samples).

Zone C, the middle zone, is divided into an upper and lower part on the basis of mineralogy. The lower part is seen in the BSE image of photos 21 and 22. Halite is prevalent, though not in the usual well-developed cubes; most of the crystals are partially to severely dissolved. Zn-bearing barite is also interspersed in this area.

The upper part of zone C is seen in the BSE images of photos 23 and 24. Besides abundant halite, three or four minerals of varying reflectivity are present in this region (e.g., photos 24 and 25). In the right center of photo 23 is a relatively large (about 20 μm) anhedral grain with slightly higher reflectivity than the background material. A high magnification BSE image of this mineral (photo 25) shows it to be partially dissolved and its original crystal form unidentifiable. An EDS spectrum of this mineral yields K, Cl and a trace Fe and is identified to be sylvite. The first bright grain up from the sylvite (to the right of center in photo 25) was also analyzed. Its EDS spectrum yields Cu, S, and minor Fe and Cl (from the matrix?) and again, cannot be positively identified. In photo 24, the upper center highly-reflective agglomerate was analyzed. Its EDS spectrum yields Cu, S, and Ag. This mineral has not yet been identified--the weight percent Ag and S are in approximately equal proportions and the weight percent of Cu is about twice that of the S. Another mineral, with a reflectivity slightly higher than background material, located in the lower left corner of photo 28 looks almost like it is in rosette form. An EDS spectrum of this mineral yields Zn, Fe, O, Cl, S, and some Si (probably from the matrix). This mineral also hasn't been identified.

The crystallization history of this sample appears fairly complex. Zone C of this sample seems to define a gradational zone between the bottom zone, B (the pipe surface), and the top zone, A (the solution surface). Bounding the pipe surface is a Zn-bearing barite-rich layer with a dense, amorphous "matrix." The boundary between zone B and C is abrupt. Zone C is characterized by abundant partially to greatly dissolved halite in a Fe, Si-rich matrix. However, the quantity and type of sulfur-bearing minerals vary through zone C. Starting at the boundary with zone B, Zn-bearing barite is present but in a considerably smaller quantity than in zone B. Going up, a Cu, S, Ag mineral and Zn, Fe, O, Cl (matrix?), S mineral are present, both unidentified as yet. At the top, relatively large (~20 μm), greatly dissolved sylvite is present as well an unidentified Cu,Fe sulfide mineral. The boundary between zone C and zone A

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is abrupt. Zone A, the solution surface, is Ag- and Cl-rich. It is characterized by halite, Ag-bearing covellite, and acanthite (AgCl).

Sample 8DS

Sample 8DS is salt scale taken from a control valve, run B, on a downstream gasket. In hand sample it is dark, vitreous and thin, almost shale-like, with a reddish-brown coating on one surface and a yellow-brown coating on the other. On many pieces one surface is corrugated, but this surface is sometimes reddish-brown and sometimes yellow-brown. On the SEM sample, the corrugated surface appears to be yellow-brown (its difficult to tell through the carbon coating).

8DS was analyzed in cross-section with the SEM, and polaroid photographs of BSE and SE images were taken. In the BSE image of photo 26, the sample is oriented so that the corrugated or pipe surface is up (at the top of the photograph) and the solution surface is down. 8DS was divided into three zones, labelled A, B, and C in the order that they were to be analyzed: zone A is the top layer of alternating bright and dark bands; zone B is the bottom layer containing highly reflective material; and zone C is the entire area between zones A and B.

Zone A, photo 27, is characterized by two bands containing a highly reflective material separated by a band of a dark, non-crystalline material. EDS analyses of the bright bands reveals the presence of two different minerals; one in the form of rosettes and less commonly compact masses and the other in cubic (appearing) form (photos 28 and 29). Typical EDS analysis of the rosettes and compact masses yields Cu, S, and minor amounts of Ag and Fe. The crystal forms and EDS spectrum suggest that this mineral is covellite (CuS). A typical EDS analysis of the cubic-looking mineral yields Ag, Cl, minor Cu and a trace Fe. The crystal form and EDS spectrum of this mineral suggest that it is chlorargyrite (AgCl). The general matrix spectrum in this sample is O, Si, Fe, and minor Cl. In all cases in zone A, the covellite and chlorargyrite are closely associated.

Zone B (e.g., photo 30) is also characterized by the covellite and chlorargyrite, but here the covellite occurs exclusively as compact masses (e.g., photo 31) and the chlorargyrite is not as common. Clusters of barite needles, an EDS analysis of which generally yields Ba, S, O, and a trace of Sr, Fe, and Ca, are also found interspersed throughout this zone (photo 30).

Zone C is predominantly non-crystalline material with the characteristic matrix constituents of O, Si, Fe and minor Cl. One subhedral halite crystal was found; more crystals are probably present, but because they don't occur as well-developed cubes in this zone (or entire sample), they are difficult to spot. One euhedral crystal containing Ca, S, O (i.e., gypsum or anhydrite) was also located. Fine barite needles are also present in this zone though they are fairly sparse. Spots of high reflectivity are also interspersed in zone C (photo 26). An EDS analysis of these rather scarce bright spots yields Ag, S, minor Cu, and a trace Fe. The high magnification BSE images of these areas, photos 32 and 33, and the EDS spectra suggest that this mineral is acanthite (Ag₂S).

A clear crystallization history can be defined from this analysis. Directly against the pipe, a tarnish (not analyzed here) formed followed by a layer rich in chlorargyrite (+ Cu) and covellite. This Cu- and Ag-rich layer was followed by a large zone (zone C) of predominantly amorphous O, Si, Fe, Cl-rich material (pre-cursor clay?) with the occasional sulfide and sulfate minerals barite and acanthite. The outside layer (comprising the solution surface) is similar to zone

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A; it contains covellite and chlorargyrite, but barite is also present making this outside layer more S-rich.

Sample 13S

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Sample 13S is mud taken from a 2 inch mud layer near a gauge on a pond bank. In hand sample it consists of a layer of yellow-red crystals around a gelatinous or moist-appearing center (SAR); in fact, when preparing it for the SEM, it took twelve hours to pump down the bell jar of the carbon coater to vacuum, so it must contain considerable moisture.

13S was analyzed in cross-section with the SEM, and polaroid photographs of BSE and SE images were taken. From the BSE image of photo 34, 13S was divided into 3 zones. Zone A is the topmost, dark area of photo 1. This zone is not continuous across the sample; it begins on the left side and continues about two-thirds of the way across. Zone B begins just below zone A and is characterized by the large halite crystals and masses of a highly reflective material. Zone C is the lowermost layer. It is overhung in the center and left of the sample by zone B, but comes about even with the face on the right one-third of the sample. As in zone B, zone C contains large halite crystals, but is distinguished from zone B by the presence of a relatively large, cubo-octahedral mineral having high reflectivity.

Zone A (e.g., photos 35 and 36) is characterized by relatively large (~100 mm), well-developed cubic halite crystals that are very pure. Associated with the halite is smaller (~10 mm), relatively highly reflective sylvite, an EDS analysis of which typically yields Cl and K with minor amounts of Mn and Na. Well-developed needles of barite (up to 10 mm in length) and very small spheres rich in fluoride (photo 42) are also present. A typical EDS analysis of barite needles yields Ba, S, O, \pm Cl (The Cl is probably from the "matrix"). The small, fluoride-rich spheres are always less than 3 mm in diameter and a clean EDS analysis of them was impossible. A typical spectrum shows peaks of F, O, Ca, Si, Cl, S, K, and a trace Fe. Although there is no hard evidence (SEM or XRD) to support a determination of this mineral, fluorite has come up as a possibility. An EDS analysis of the amorphous matrix was also made. The matrix consists primarily of O, Cl, Ca, and Si; an element signature characteristic of the matrix throughout the sample.

In all areas of zone A, halite is considerably larger than the other minerals. The sylvite occasionally occurs as well-developed cubo-octahedral crystals (photo 38), but more commonly shows dissolution textures such as hollowed centers and rounded corners (photos 35 and 36). The barite appears to be associated with the sylvite, and the fluoride-rich spheres seem randomly distributed throughout the matrix.

Photo 39 is a BSE image of an area representative of zone B. EDS analyses and high-magnification images (e.g., photos 45 and 46) of the massive, highly reflective material indicate that it is sylvite. Well-developed cubo-octahedral sylvite crystals are rare in this zone, but when present, always occur with halite (photo 18). The sylvite most commonly occurs here as masses of partially-dissolved crystals (i.e., they have obvious dissolution textures; photos 40 and 41). Cubic halite crystals and fluoride-rich spheres are much less common in this zone and apparently no barite is present.

Zone C is characterized by the presence of both the massive, partially-dissolved sylvite and the well-developed cubo-octahedral crystals. Halite is in greater quantity in this zone than zone B and is closely associated with the sylvite. Neither barite nor the fluoride-rich spheres was found in this zone, but a

Ca,S-rich mineral intergrown with halite was discovered (photo 42). An EDS analysis yields Ca, S, and O, and upon heating by the beam, a crack developed and grew (photo 43) suggesting the presence of water. The evidence suggests that this mineral is gypsum.

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Test Run Conditions

The system pipes were "fairly clear but not cleaned out" before the January 1988 test runs⁴. Thus, it is not known whether all of the scale collected resulted from these runs. Previous test runs had been made (Thompson and Fournier, 1988⁵). The 19-day step-rate flow test consisted of 3 fairly stable rate-steps during the first 13 days after which an attempt to achieve a stable higher rate was largely unsuccessful, with a constant slightly higher rate achieved only during the last 25 hours.⁶ There is also the possibility of precipitation during cooling and standing of the system. Because of these uncertainties, no attempt will be made to correlate layering in scale samples with rate-steps during the 1988 test. The samples are considered interesting because they document scale compositions and textures that may be encountered in such a system.

Temperature at the wellhead was about 255°C (492°F). (Flash initiation occurred at about 3,200 ft. at about 300°C or 570°F.) Temperature calibrations in the system were done at operating conditions during the test, giving a temperature at the separator of 207°C to 209°C (400-409°F) during the course of the first three rate-steps. The separator was run at a pressure of 200 psig.

Brine samples were taken on June 3, 4, and 5 from the two-phase flowline near the wellhead. An additional sample of brine was taken from the weirbox on June 5. At the time of these samplings, the steam separator was not in operation. Flowline samples were taken with a Teflon-lined probe/cooling coil assembly. Access was through a gate valve on the flowline about 40 feet from the wellhead. The probe, 1/4-inch stainless steel, was inserted into the flow space of the flowline through an access valve assembly located at a 3-o'clock position on the horizontal flowline. Sampling of the brine fraction without steam was successful. The weirbox sample was obtained by dipping a container into the active flow stream. Flowline temperatures at the sampling point were essentially those of the wellhead, near 255°C (492°F). Pressures in the flowline ranged from 503 to 513 psig. The weirbox was at atmospheric pressure; no temperature is given.

Fluid compositions are shown in Table 5. The first three columns are the flowline brine compositions on June 3, 4, and 5, corrected for ion charge balance and for the dilution and acidification of the samples. The fourth column is the weirbox brine composition corrected, in addition, for precipitation. The fifth and sixth columns show calculated pre-flash fluid compositions based on the flowline and weirbox samples respectively; the data show good consistency.

The adjustments made to the weirbox brine composition to compensate for precipitation in the line required the addition of 490 mg/kg silica, 133 mg/kg iron, 7.9 mg/kg lead, 3.5 mg/kg arsenic, 1.4 mg/kg cadmium and 1.1 mg/kg

⁴Personal communication from Frank Cochrane at Bechtel National, Inc.

⁵Thompson, J. M., and R. O. Fournier, 1988, Jour. Geophys. Res., v. 93, No. B11, P. 13,165-13,173

⁶This and other test information is from the Well Test Engineering Report on the State 2-14 Well Test, June 1- June 25, 1988, Salton Sea Scientific Drilling Program, for Bechtel National, Inc., by Mesquite Group, Inc.

copper; these constitute relatively high percentages of the original amounts present. Large quantities of sodium chloride were observed to precipitate in the weirbox during atmospheric flash.

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Discussion

The bulk chemical analyses of the scale samples (Table 2) can be roughly divided into those high in major elements Si and Fe and those high in Na and Cl. The first are from the line and the second from the pond. Tables 2 (Major Elements) and 3 (Minor Elements) also include samples taken before the high pressure separator and samples taken from the lines beyond it. A little more copper and silver may precipitate in the line before the high pressure separator.

Figures 2-5 make it easier to see what elements are present in the lines and in the pond. The interesting thing is how many elements are present; this is also shown by the number of different phases reported in the SEM data.

In the lines, in addition to Si and Fe, we see the major elements, Na, Cl, K, Ca, and S. We also see a relatively large amounts of Cu and Ag, and a little Pb and Zn. In the pond, in addition to Na and Cl, there are significant amounts of Fe, Si, Sr, Cu, Pb, Zn, Cd, As, Sb, and Li.

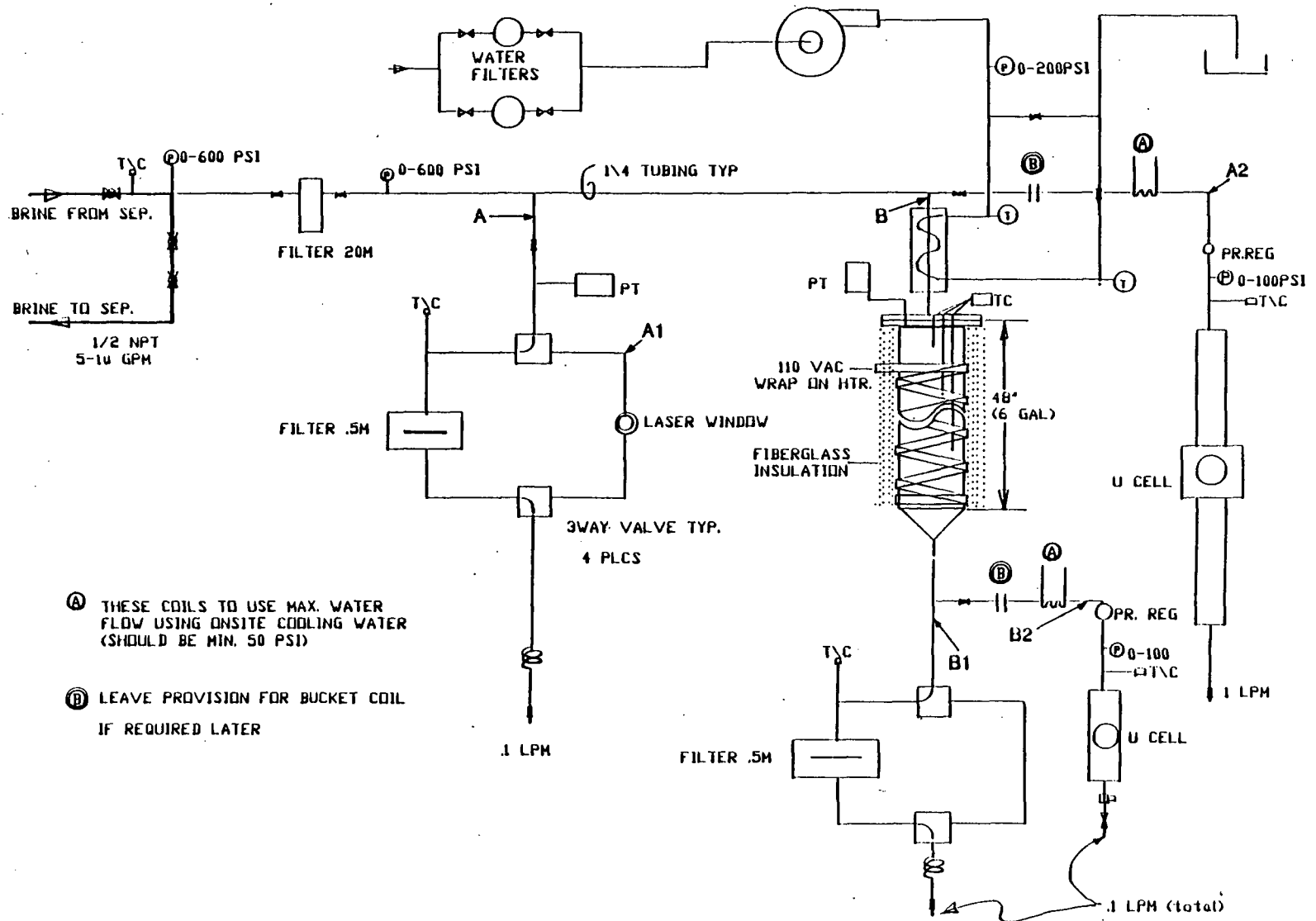
The x-ray diffraction analyses (Table 4) show that halite (NaCl) is present in significant amounts in the lines as well as in the ponds, that sphalerite (ZnS) and magnetite (Fe_3O_4) are also present, and that chalcopyrite (CuFeS_2), sylvite (KCl), and silver (Ag) may be present. X-ray diffraction analyses detect only relatively large amounts of crystalline material, roughly over 5% by weight. The fact that they do not generally show silicon- and iron-bearing phases indicates that the abundant Si and Fe must occur in amorphous material.

The Scanning Electron Microscope (SEM) analyses are much more sensitive to what phases are present in the scale and are particularly interesting. Table 6 summarizes the SEM analyses and includes summaries of the other data for comparison. The SEM analyses show the samples to be layered, as would be expected from multiple runs under multiple conditions. There are only slight similarities in the layering from sample to sample; it is not possible to correlate layers with certainty. The most similar are samples 8C and 8D, which were taken from the upstream and downstream sides of the control valve in line B. Differences may be caused by varying run conditions, by episodes of local erosion, and by use of different lines for different runs. Thus it is not possible to document the scale pattern throughout the system for any single run.

The interesting features are the following: 1) Some amorphous (non-crystalline, somewhat glassy) Fe-, O-, and Si-bearing scale is nearly everywhere, even in the pond. Other chemical components also constitute part of the amorphous scale. 2) Halite also seems to be nearly ubiquitous. 3) Barite is common; 4) Magnetite precipitates at the high-temperature end of the line. 5) Sulfides appear throughout the piping, with zinc and lead sulfides predominating at the hotter end and copper and silver towards the cooler end. 6) In addition to halite (NaCl), the chlorides of potassium and silver also precipitate.

In general, in this Salton Sea brine system, the scale consists of a large number of different amorphous and crystalline phases, which vary significantly with run conditions.

3.3



5\5\88 RGS

FIGURE 3.1. Schematic of Test Stand

Table 1: DESCRIPTION OF THE SCALE SAMPLES

| Sample | Label Description | Additional Observations |
|--------|---|---|
| 1 | Downstream HP separator isolation valve; pipe coating. | Chunks of botryoidal dull black scale; brown coatings |
| 2 | Downstream HP isolation; scale on bottom of pipe-- loose crust on bottom. | Flat black scale (2.0 cm square) with small reddish cubes intermingled in bag. |
| 3 | Isolation valve HP separator valve seat. | Two pieces of flat black scale; botryoidal forms; rusty coatings. |
| 4 | HP isolation valve; concave valve face. | Square chunks (1.5 cm) of dull black scale with rusty coatings. |
| 5 | HP isolation valve; pipe on concave side of valve. | Chunks of scale from 2.5 cm to 3.0 cm in diameter; dull black surface coated with red and yellow drusy material. |
| 7A | Control valve, run A; pipe upstream. | Crumbly specular black scale coated with drusy 'rust'. |
| 7B | Control valve, run A; pipe downstream. | Chips of dull black scale with light red coating |
| 8A | Control valve, run B; pipe downstream. | Similar to 8C; chunks are coated with specular rind or small (<1mm) cubic crystals. |
| 8B | Control valve, run B; pipe downstream. | Similar to 8c with rusty coating on outside curved surface against the pipe. |
| 8C | Control valve, run B; gasket upstream. | Chunks of scale up to 2.5 cm long by 1 cm wide by 0.5 cm thick; some scales curve to reflect deposition on piping. Interlayered vitreous, black material and rusty, crystalline material. |
| 8D | Control valve, run B; gasket downstream. | Chunks of scale from 1.5 cm long by 0.75 cm wide by 0.25 cm thick; similar to 8C in appearance. |
| 10 | Exit of weir box liquid stream | Buff-colored clasts from 2.5 to 1.0 cm diameter; coatings of reddish cubes. |
| 11 | Salt scale below and to side of weir box; may be caused by mixing ditch waters; beneath 12. | Large (5-6 cm) chunk of green to clear scale with vitreous luster. Two layers visible. |
| 12 | Salt scale below and to side of weirbox; may be mixed with ditch water; above 11. | Large (5-6 cm) chunks of stratified white and clear scale; cubes and possible rhombs up to 3 mm size. |
| 13 | Mud on pond bank by gauge, about 2 in. thick; is above salt scale samples 14 and 15. | Reddish, moist-appearing clay with occasional cubic crystals. |
| 14 | Salt scale pond bank beneath 13 (mud) near pond gauge. | Large cubes (5 mm) of clear scale on tannish clay layer. |
| 16 | Scale on pond bank near southeast corner of pond. | Tan to buff-colored crystals approx. 1 mm in diameter. Cubic forms. |

Table 2: MAJOR ELEMENTS IN WEIGHT PERCENT

| Sample | Na | K | Ca | Mg | Fe | Al | Si | Ti | P | Ba | Mn | Cl | S | LOI |
|--------|-------|------|------|------|-------|------|-------|------|------|------|------|-------|------|-------|
| 1C | 1.52 | 1.39 | 0.91 | 0.09 | 12.43 | 2.59 | 19.02 | 0.00 | 0.00 | 0.01 | 0.82 | 0.61 | 4.19 | 9.53 |
| 2C | 8.41 | 1.81 | 2.82 | 0.37 | 26.93 | 0.29 | 4.15 | 0.00 | 0.00 | 0.03 | 0.51 | 18.70 | 6.15 | 7.43 |
| 3C | 2.16 | 1.79 | 1.67 | 0.15 | 17.43 | 2.32 | 21.46 | | 0.00 | 0.04 | 1.06 | | | 5.96 |
| 4C | 4.08 | 1.36 | 3.43 | 0.08 | 15.17 | 0.13 | 18.27 | 0.00 | 0.00 | 0.01 | 0.94 | 11.40 | 4.82 | 17.40 |
| 5C | 1.74 | 1.34 | 1.35 | 0.08 | 15.13 | 1.86 | 19.07 | 0.00 | 0.00 | 0.05 | 1.04 | 2.70 | 2.75 | 10.20 |
| 7AC | 3.97 | 1.98 | 3.93 | 0.18 | 18.97 | 0.05 | 15.10 | 0.00 | 0.00 | 0.01 | 1.11 | 13.50 | 1.80 | 20.70 |
| 7BC | 0.45 | 0.25 | 0.94 | 0.12 | 26.45 | 0.06 | 20.42 | 0.00 | 0.00 | 0.01 | 1.42 | 0.85 | 0.17 | 16.30 |
| 8AC | 2.21 | 1.11 | 1.58 | 0.21 | 21.31 | 0.47 | 17.81 | 0.00 | 0.00 | 0.02 | 1.30 | 4.88 | 0.83 | 19.70 |
| 8BC | 1.14 | 0.61 | 0.65 | 0.24 | 22.57 | 0.36 | 20.47 | 0.00 | 0.00 | 0.01 | 1.55 | 1.63 | 0.45 | 15.10 |
| 8CC | 4.04 | 1.49 | 2.30 | 0.22 | 20.60 | 0.29 | 16.03 | 0.01 | 0.01 | 0.10 | 0.87 | 9.80 | 0.37 | 19.90 |
| 8DC | 1.30 | 0.71 | 0.88 | 0.20 | 22.07 | 0.56 | 19.21 | 0.00 | 0.00 | 0.02 | 1.50 | 1.88 | 1.10 | 13.20 |
| 10C | 23.99 | 2.52 | 4.69 | 0.02 | 2.55 | 0.02 | 5.09 | 0.00 | 0.01 | 0.22 | 0.26 | 42.00 | 0.12 | 16.60 |
| 11C | 39.10 | 0.06 | 0.10 | 0.01 | 0.03 | 0.02 | 1.50 | 0.00 | 0.00 | 0.04 | 0.01 | 59.60 | 0.00 | 0.67 |
| 12C | 39.90 | 0.07 | 0.07 | 0.01 | 0.03 | 0.02 | 1.50 | 0.00 | 0.00 | 0.04 | 0.02 | 60.70 | 0.00 | 0.41 |
| 13C | 17.86 | 3.12 | 6.54 | 0.03 | 1.71 | 0.07 | 3.81 | 0.00 | 0.01 | 0.19 | 0.34 | 40.40 | 0.08 | 25.40 |
| 14C | 37.89 | 0.53 | 0.81 | 0.08 | 0.29 | 0.32 | 1.15 | 0.01 | 0.01 | 0.10 | 0.04 | 56.80 | 0.01 | 3.61 |
| 16C | 39.41 | 0.09 | 0.15 | 0.01 | 0.02 | 0.02 | 1.50 | 0.00 | 0.00 | 0.02 | 0.01 | 60.10 | 0.00 | 0.92 |

The samples have been grouped by sampling location. The first were taken before the high pressure separator, the second from the lines beyond it, and the third below the weir box.
LOI stands for Loss on Ignition and is the weight percent of water in the sample.

Table 3: MINOR ELEMENTS IN PPM

| Sample # | Sr | Cr | Co | Ni | Cu | Pb | Zn | Cd | Ag | As | Sb | Sn | Li | Be | Zr | La | Ce | Hg |
|----------|-----|-----|----|----|--------|------|------|-----|-------|------|------|----|-----|-----|----|----|----|----|
| 1C | 131 | | 20 | 18 | 102000 | 2349 | 530 | 14 | 34020 | 656 | 810 | 19 | 49 | 141 | 28 | 6 | | 6 |
| 2C | 358 | 89 | 34 | 37 | 13696 | 5814 | 4550 | 616 | 382 | 4387 | 268 | 23 | 165 | 11 | | 13 | | 4 |
| 3C | 237 | 250 | | 12 | 27228 | 983 | 2495 | 23 | 7412 | 351 | 244 | 21 | 116 | 157 | | 9 | | |
| 4C | 356 | 5 | 18 | 15 | 5259 | 1744 | 559 | 10 | 643 | 922 | 1272 | 9 | 168 | 40 | | 10 | | 6 |
| 5C | 200 | | 5 | 18 | 113800 | 936 | 675 | 14 | 37590 | 1006 | 852 | 15 | 74 | 152 | 34 | 7 | | 7 |
| 7AC | 510 | | 3 | 14 | 2120 | 125 | 523 | 11 | 485 | 324 | 76 | 10 | 263 | 101 | | 16 | 13 | 5 |
| 7BC | 66 | | 3 | 15 | 1282 | 224 | 342 | 14 | 235 | 494 | 611 | 16 | 29 | 174 | | 8 | | 5 |
| 8AC | 215 | | 2 | 16 | 19900 | 182 | 436 | 12 | 4402 | 395 | 369 | 32 | 117 | 217 | | 9 | | 7 |
| 8BC | 81 | | | 14 | 10578 | 116 | 265 | 11 | 2432 | 526 | 617 | 12 | 58 | 271 | | 8 | | |
| 8CC | 329 | 18 | 3 | 25 | 3877 | 125 | 2627 | 13 | 981 | 379 | 227 | 12 | 160 | 150 | | 13 | | 5 |
| 8DC | 112 | 10 | 69 | 22 | 25346 | 342 | 442 | 12 | 16078 | 1145 | 2829 | 13 | 63 | 281 | | 6 | | 5 |
| 10C | 698 | 3 | 1 | 7 | 95 | 2446 | 615 | 16 | 23 | 289 | 162 | | 225 | 5 | | 19 | 20 | |
| 11C | 38 | | | | | 723 | 16 | 76 | 16 | | | | 6 | | | | | 4 |
| 12C | 35 | | | | | | 772 | 17 | 12 | | | | 5 | | | | | 4 |
| 13C | 923 | 2 | 2 | 6 | 106 | 355 | 1029 | 23 | 12 | 252 | 171 | 9 | 350 | 6 | | 20 | 24 | 5 |
| 14C | 185 | 2 | 2 | 4 | 17 | 241 | 145 | 50 | 10 | 63 | | | 47 | | 19 | 9 | 17 | 4 |
| 16C | 33 | | | | | 584 | 27 | 70 | 12 | | | | 10 | | | | | 3 |

The samples have been grouped by sampling location. The first were taken before the high pressure separator, the second from the lines beyond it, and the third below the weir box.

PRELIMINARY DRAFT

Table 4: PHASES IDENTIFIED BY X-RAY DIFFRACTION ANALYSES

| Sample Number | Phases identified |
|---------------|---|
| 2S | Halite (NaCl) Sphalerite (ZnS) Magnetite (Fe ₃ O ₄) Possible Chalcopyrite (CuFeS ₂) |
| 7BS | No crystalline phases identified |
| 8Cs | Halite (NaCl) Possible Sylvite |
| 8DS | Halite (NaCl) Possible Sylvite (KCl) |
| 13S | Halite (NaCl) Possible Sylvite (KCl) Possible Silver metal |

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TABLE 5: FLUID COMPOSITIONS

| Sample # | 180 | 182 | 173 | 254 | 173 | 254 |
|---|--------------------------|--------------------------|--------------------------|-----------------------------|--|--------|
| Type | line sample taken 6/3/88 | line sample taken 6/4/88 | line sample taken 6/4/88 | weirbox sample taken 6/5/88 | Calculated pre-flash concentrations based on above samples | |
| Temp. °F | 494 | 492 | 492 | 225 | | |
| Analyses in Milligrams per kilogram (ppm) | | | | | | |
| Sodium | 56092 | 55830 | 55495 | 70702 | 52287 | 52750 |
| Calcium | 28387 | 28013 | 27795 | 35556 | 26188 | 26528 |
| Potassium | 17522 | 17387 | 17413 | 22096 | 16407 | 16485 |
| Iron | 1731 | 1730 | 1713 | 2185 | 1614 | 1630 |
| Manganese | 1528 | 1510 | 1526 | 1928 | 1437 | 1438 |
| Zinc | 527 | 522 | 526 | 665 | 496 | 496 |
| Silica | 496 | 492 | 496 | 626 | 467 | 467 |
| Strontium | 418 | 419 | 420 | 531 | 395 | 396 |
| Boron | 415 | 412 | 414 | 524 | 390 | 391 |
| Lithium | 221 | 220 | 219 | 279 | 207 | 208 |
| Ammonium | 405 | 415 | 404 | 518 | 381 | 386 |
| Barium | 111 | 116 | 132 | 152 | 124 | 113 |
| Lead | 99 | 102 | 101 | 127 | 95 | 95 |
| Magnesium | 46 | 44 | 45 | 57 | 43 | 43 |
| Arsenic | 16 | 15 | 16.3 | 20 | 15 | 15 |
| Cadmium | 3 | 2 | 2.3 | 29 | 2 | 2 |
| Copper | 2 | 2 | 21 | 2.4 | 2 | 2 |
| Chloride | 154796 | 155162 | 155042 | 196373 | 146080 | 146512 |
| Bromide | 100 | 103 | 105 | 130 | 99 | 97 |
| Sum of ppm | 262914 | 262496 | 261867 | 332474 | 246729 | 248054 |

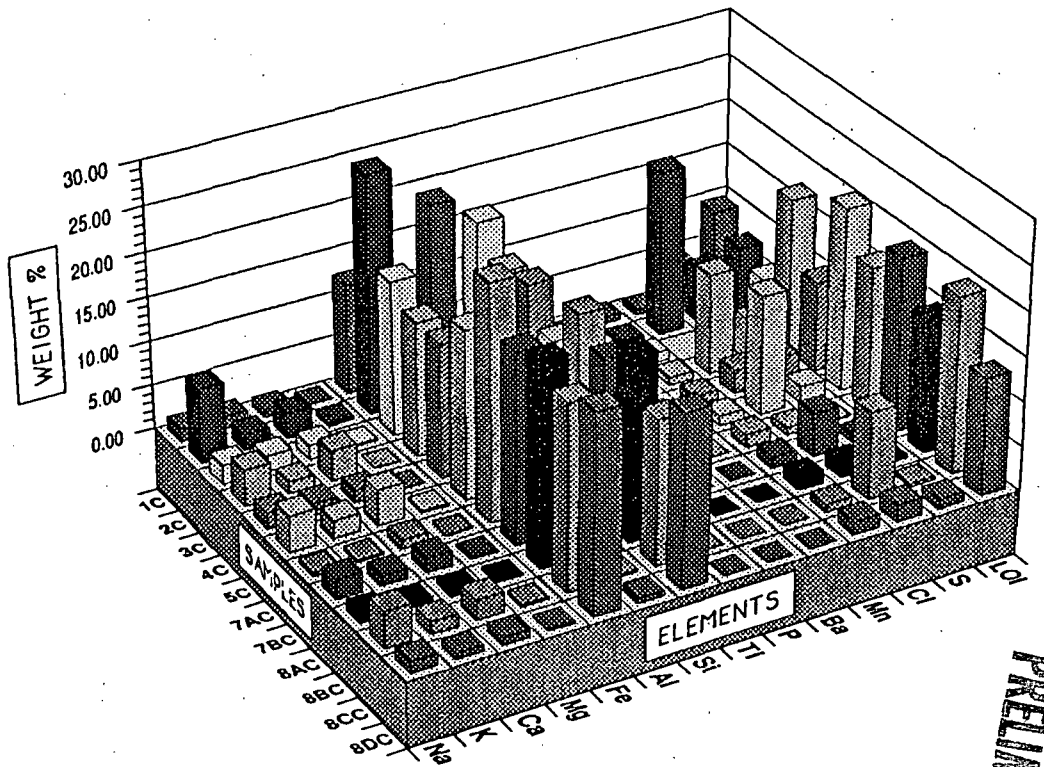
PRELIMINARY DRAFT

Table 6: SUMMARY OF ANALYSES

| Sample # | 2 | 7B | 8C | 8D | 13 |
|-------------------|---|--|---|--|--|
| Location | Downstream of the HP isolation valve | Downstream of control valve of line A | Upstream gasket of control valve of line B | Downstream gasket of control valve of line B | Mud on pond bank by gauge |
| Chemical Analyses | High Fe Moderate Na, Cl High Cu, Pb, Zn, As | High Fe, Si High Mn | High Fe, Si Moderate Na, Cl High Cu, Zn | High Fe, Si High Cu, Ag | High Na, Cl, K, Ca, Ba |
| XRD Analyses | Halite (NaCl) Sphalerite (ZnS) Magnetite (Fe ₃ O ₄) ?Chalcopyrite (CuFeS ₂) | No crystalline material in sufficient quantity to identify by XRD | Halite (HCl) ?Sylvite (KCl) | Halite (NaCl) ?Sylvite | Halite (NaCl) ?Sylvite.(KCl) ?Silver (Ag) |
| SEM Analyses | pipe side? ----- Fe, O, Cl, Si, Ca matrix ----- Sphalerite (ZnS) Galena (PbS) Fe, O, Cl, (Si), (Ca) ----- Magnetite (Fe ₃ O ₄) Fe, O, Cl, Si, Ca ----- Halite (NaCl) ?Galena (PbS) | pipe side? ----- Fe, O, Si, (Mn) ----- Barite (BaSO ₄) Fe, O, Si, (Mn) ----- Chalcopyrite (CuFeS ₂) Covellite (CuS) Fe, O, Si, (Mn) | Barite (BaSO ₄) Fe, O, Si ----- Halite (NaCl) Barite (BaSO ₄) Cu-S-Ag mineral Zn-Fe-O-S mineral Cu-Fe-S mineral Sylvite (KCl) ----- Covellite (CuS) Chlorargyrite (AgCl) | Barite (BaSO ₄) Chlorargyrite (AgCl) Covellite (CuS) Fe, O, Si, (Cl) ----- ?Halite (NaCl) ?Barite (BaSO ₄) Acanthite (Ag ₂ S) ?Gypsum (CaSO ₄ .2H ₂ O) Fe, O, Si, (Cl) ----- Covellite (CuS) Chlorargyrite (AgCl) Fe, O, Si, Cl | Halite (NaCl) Sylvite (KCl) Barite (BaSO ₄) ?Fluorite (CaF ₂) Ca, O, Si, Cl ----- Halite (NaCl) Sylvite (KCl) ----- Halite (NaCl) Sylvite (KCl) Gypsum (CaSiO ₄ .2H ₂ O) |

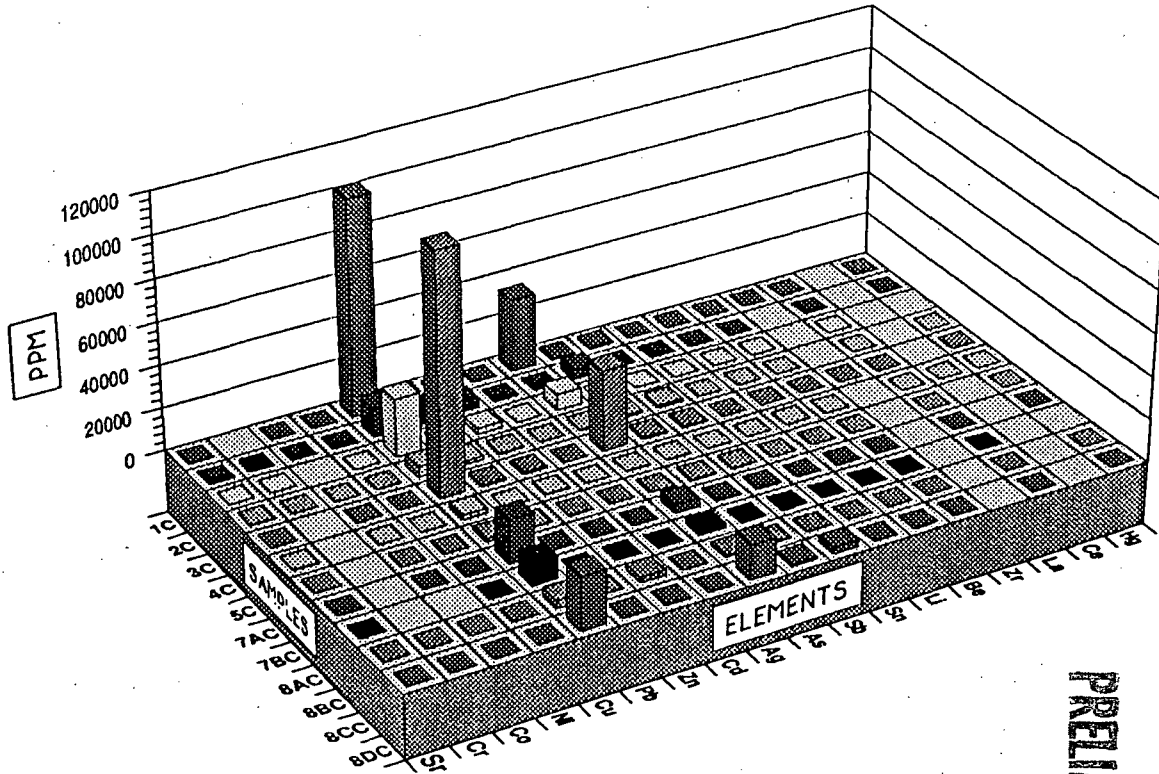
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Figure 2: MAJOR ELEMENTS IN THE SCALE IN THE LINES



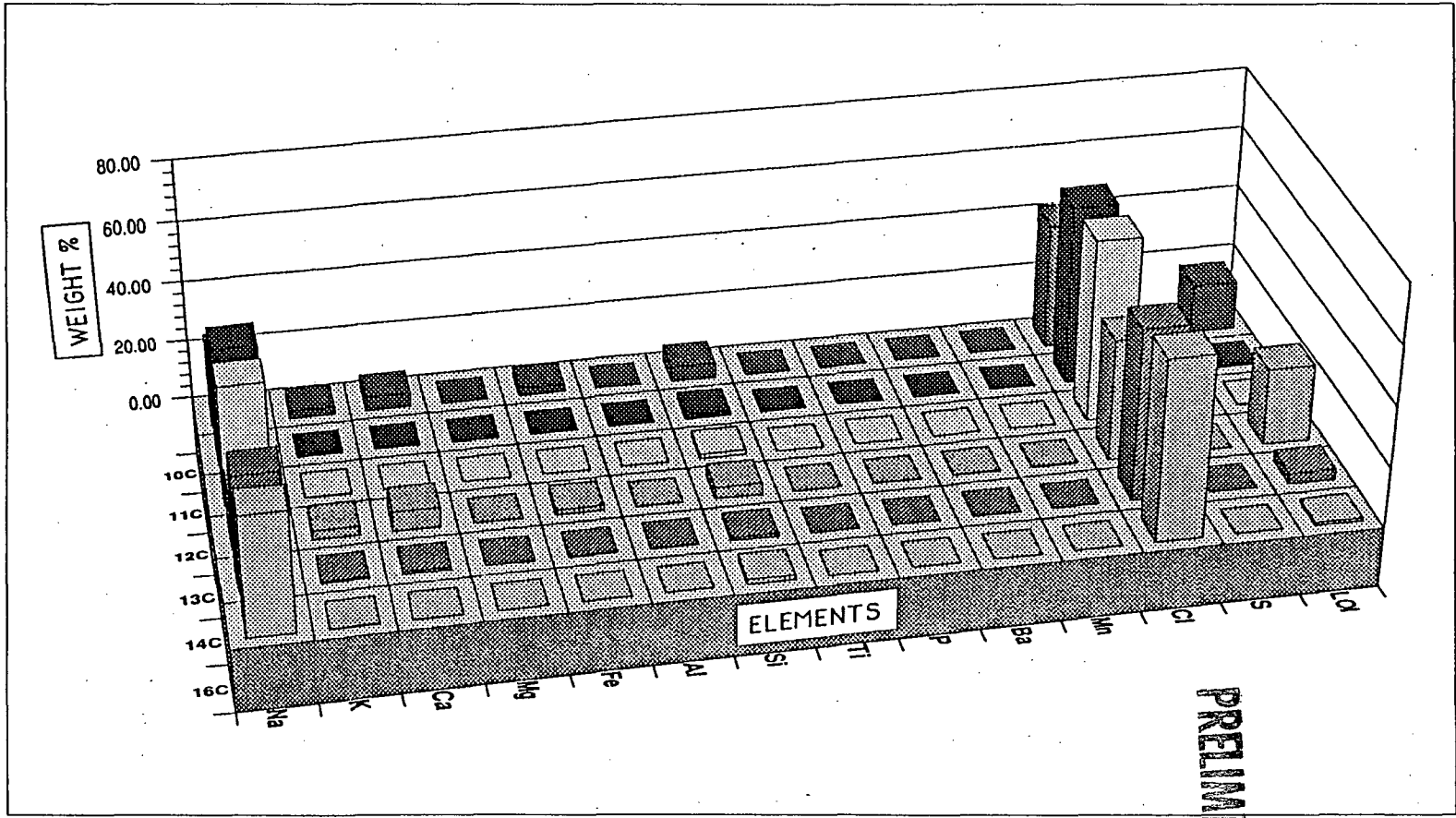
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Figure 3: MINOR ELEMENTS IN THE SCALE IN THE LINES



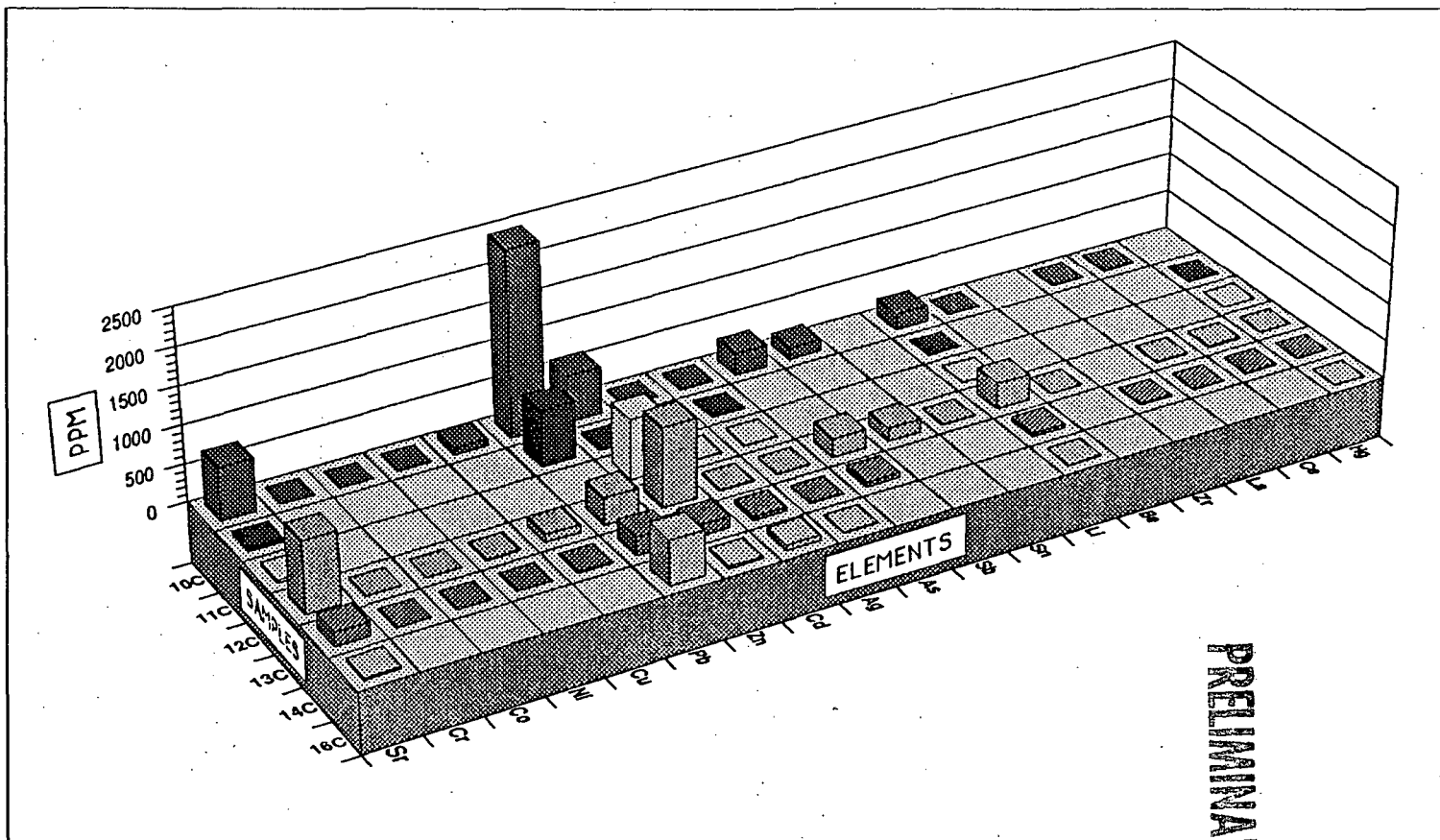
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Figure 4: MAJOR ELEMENTS IN THE SCALE IN THE POND



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Figure 5: MINOR ELEMENTS IN THE SCALE IN THE POND

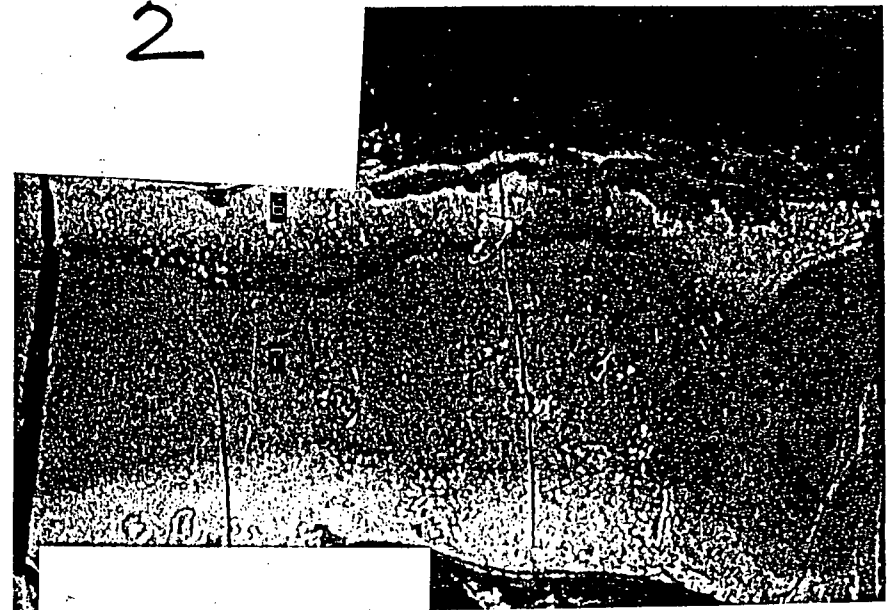


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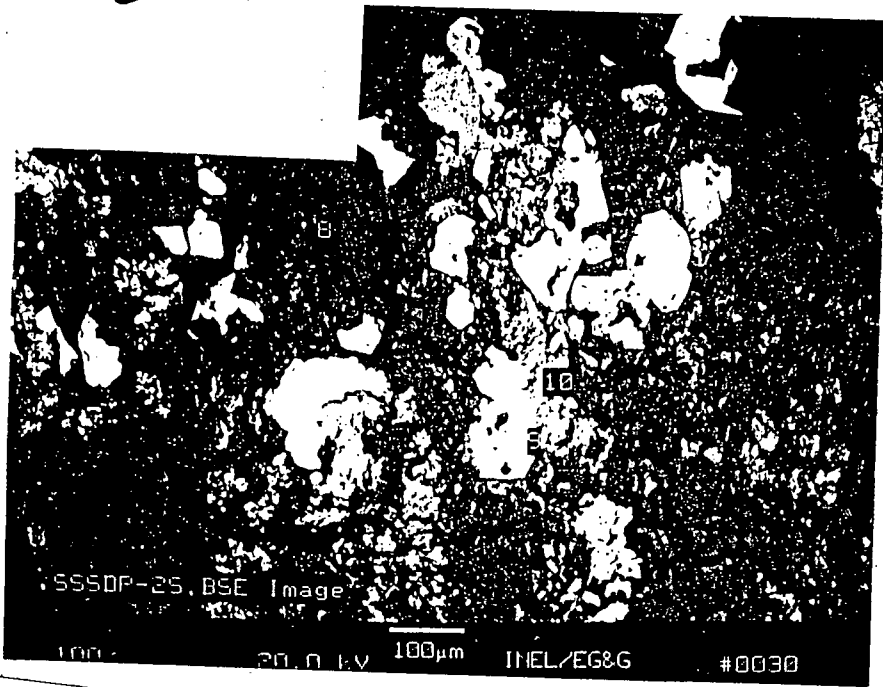
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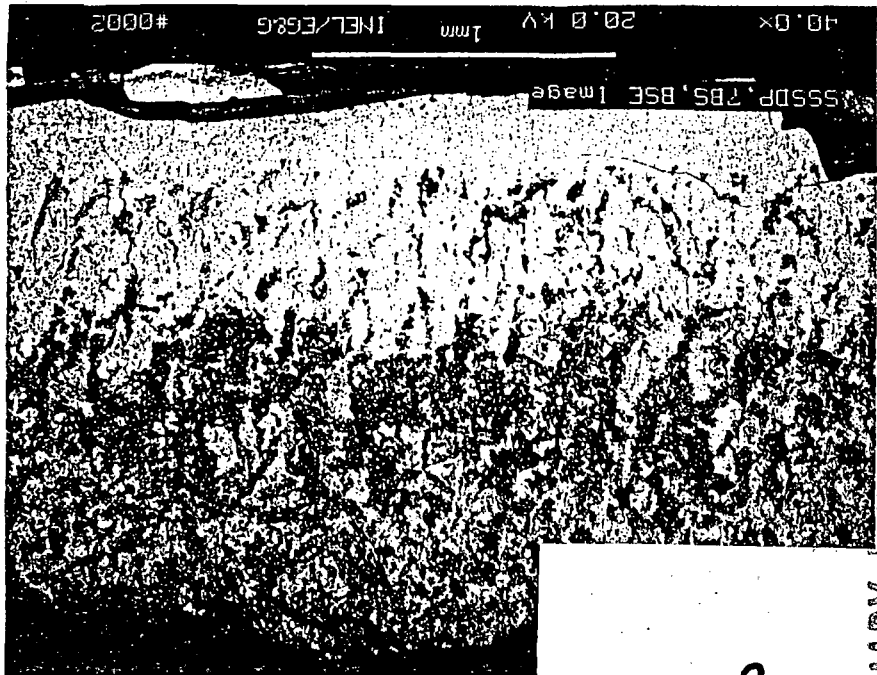


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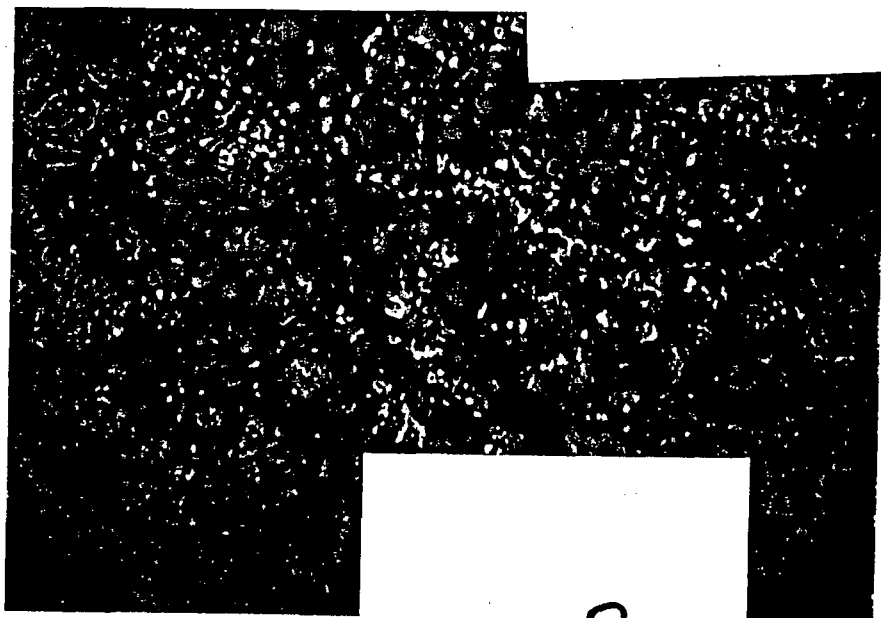
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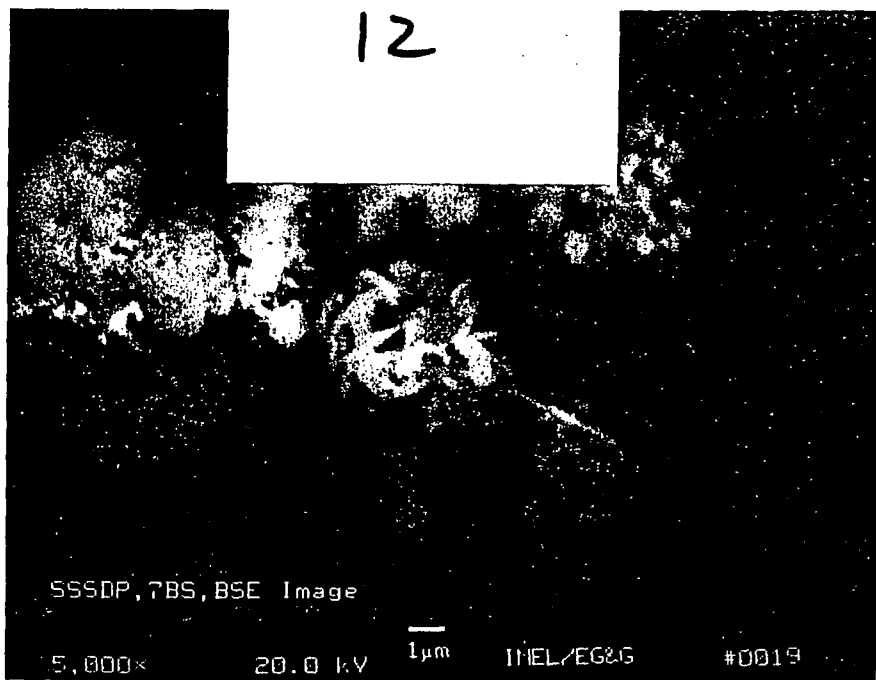
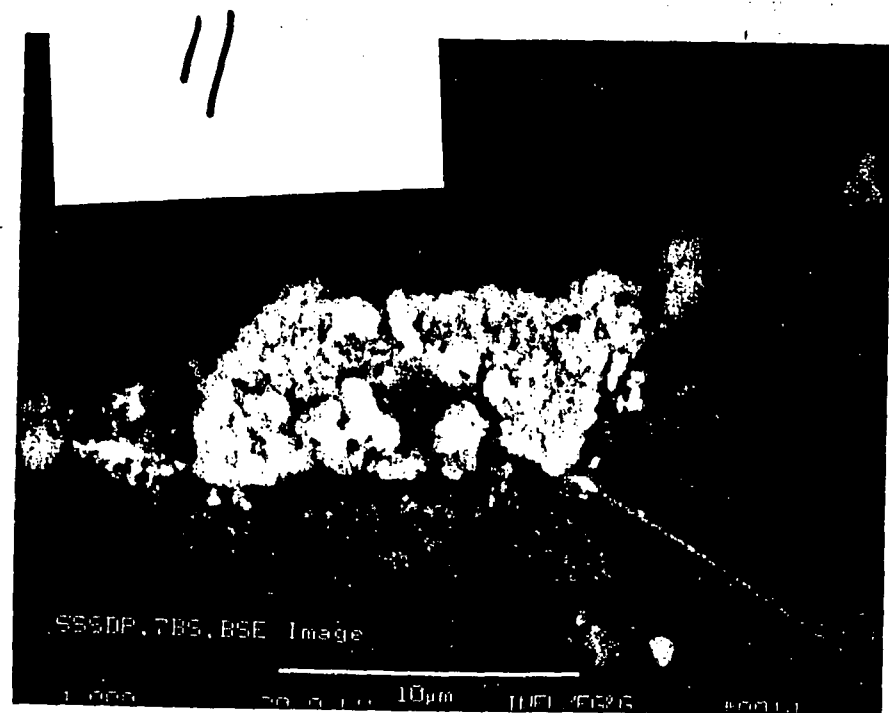
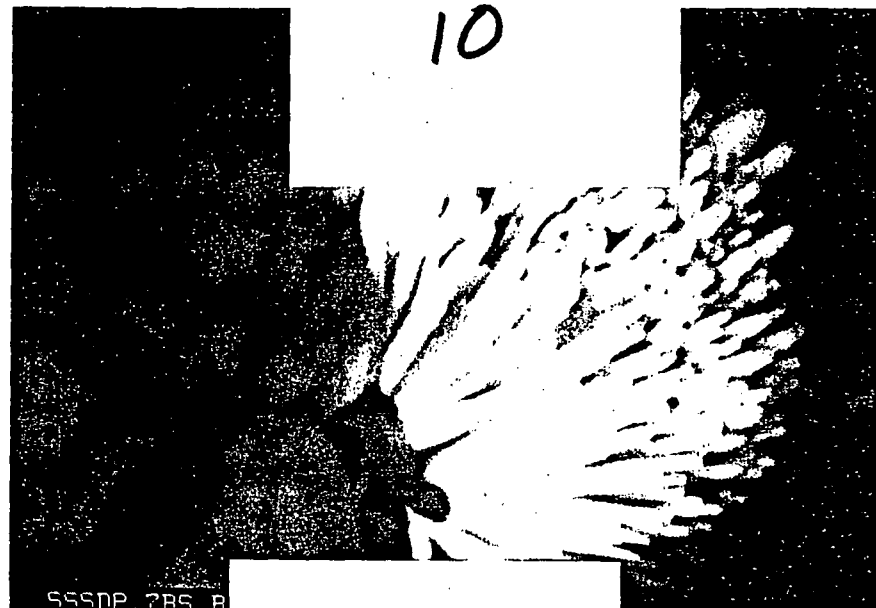
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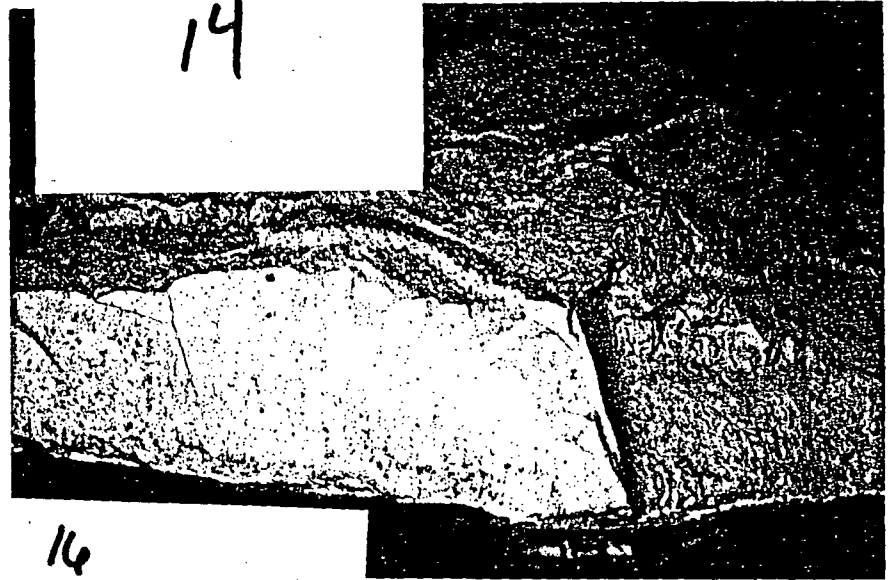
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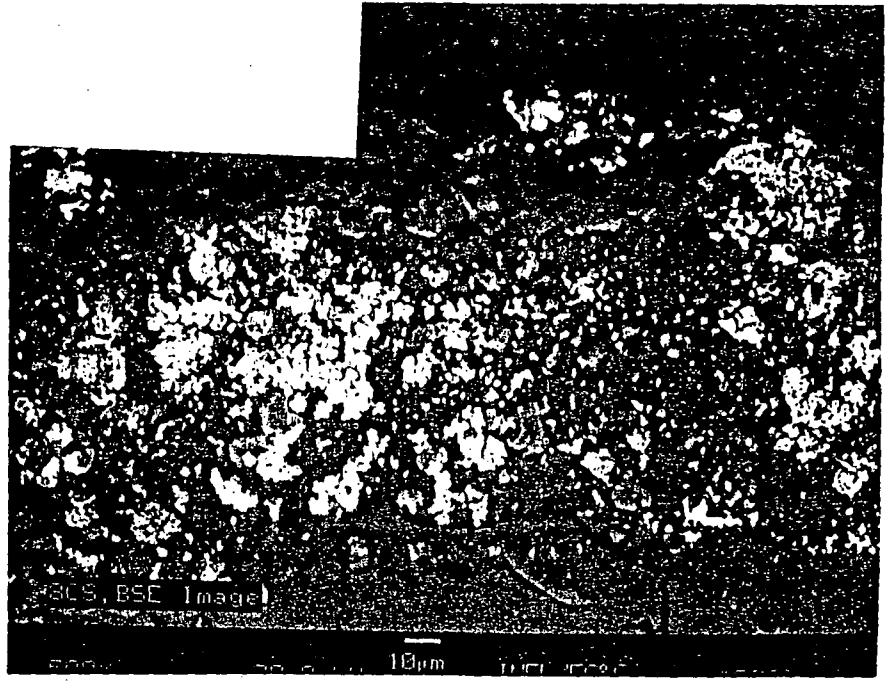
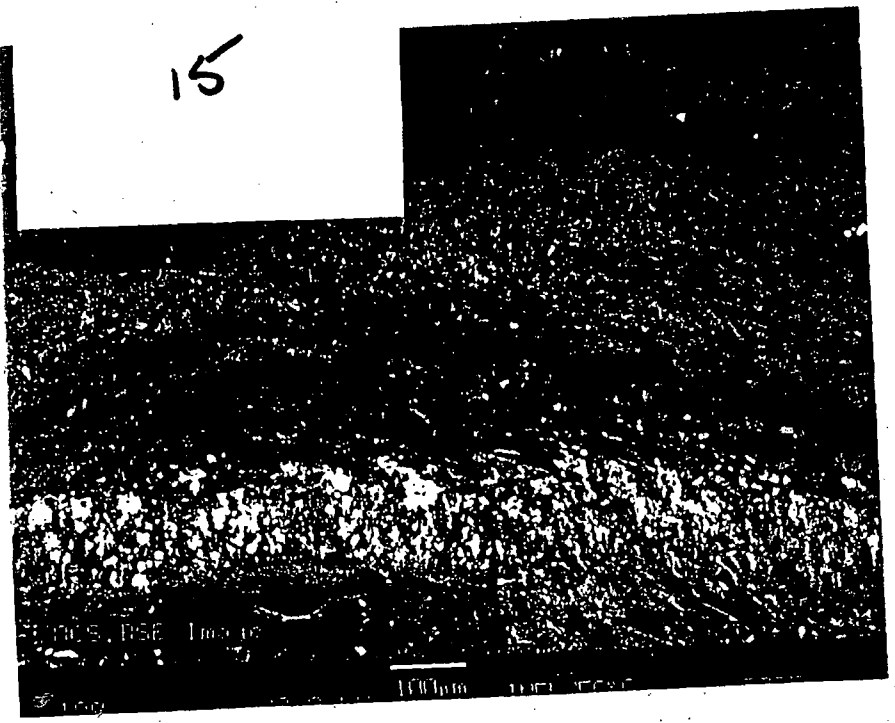
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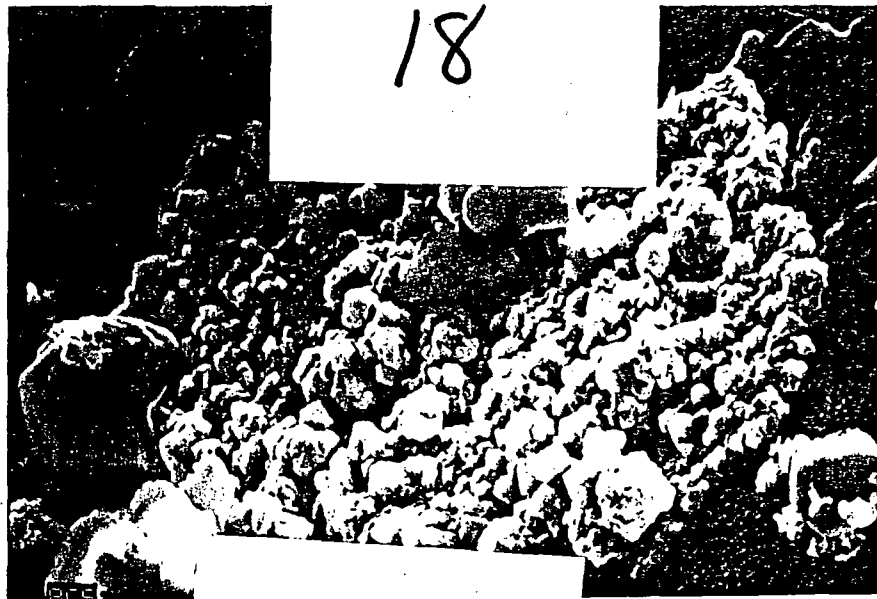
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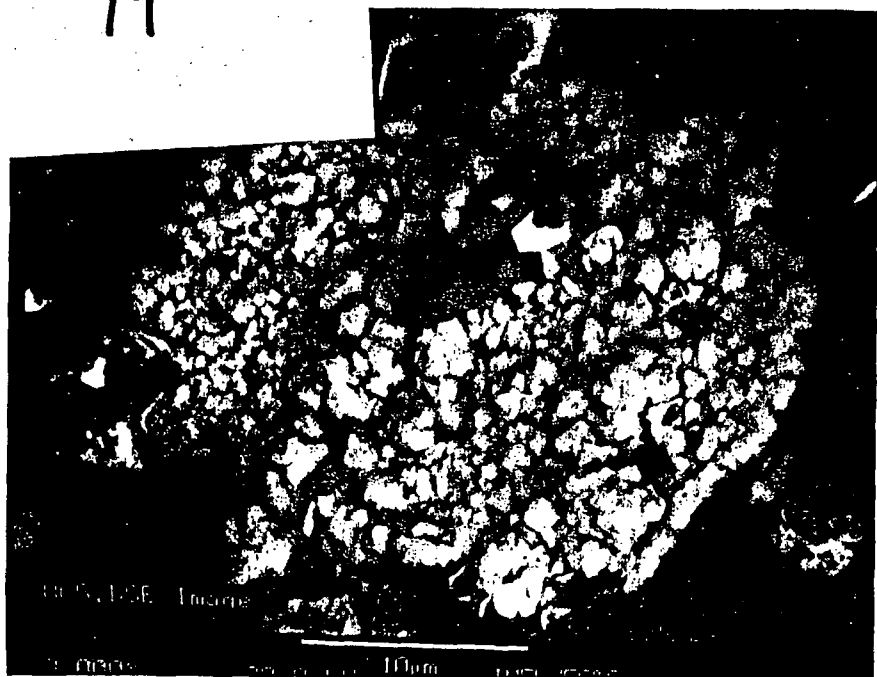


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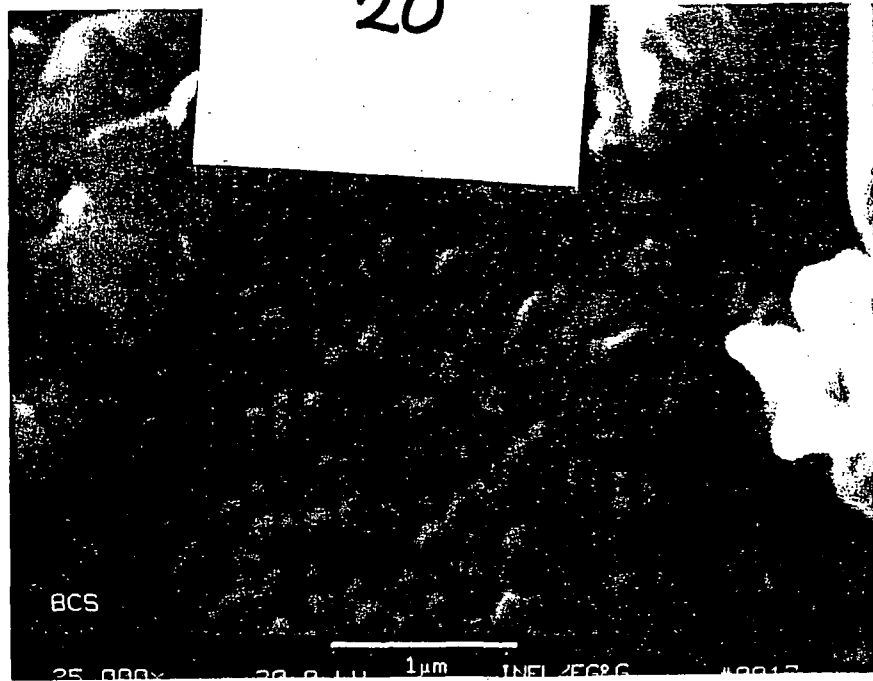


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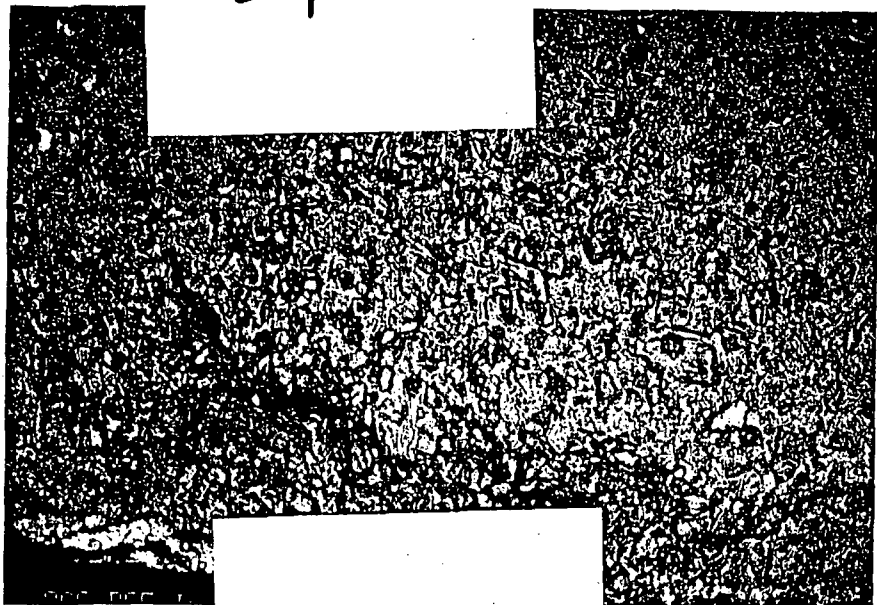
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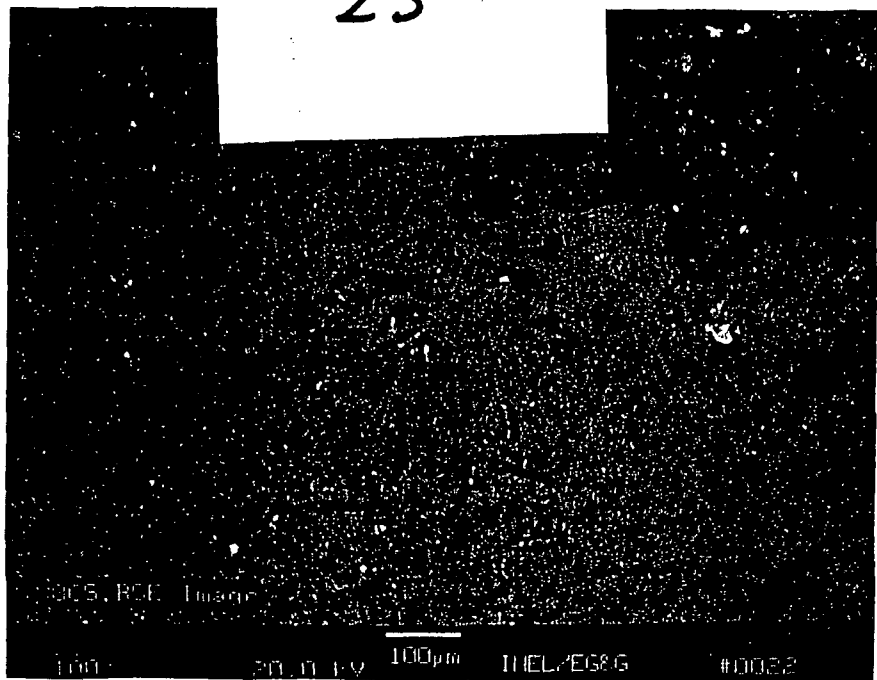
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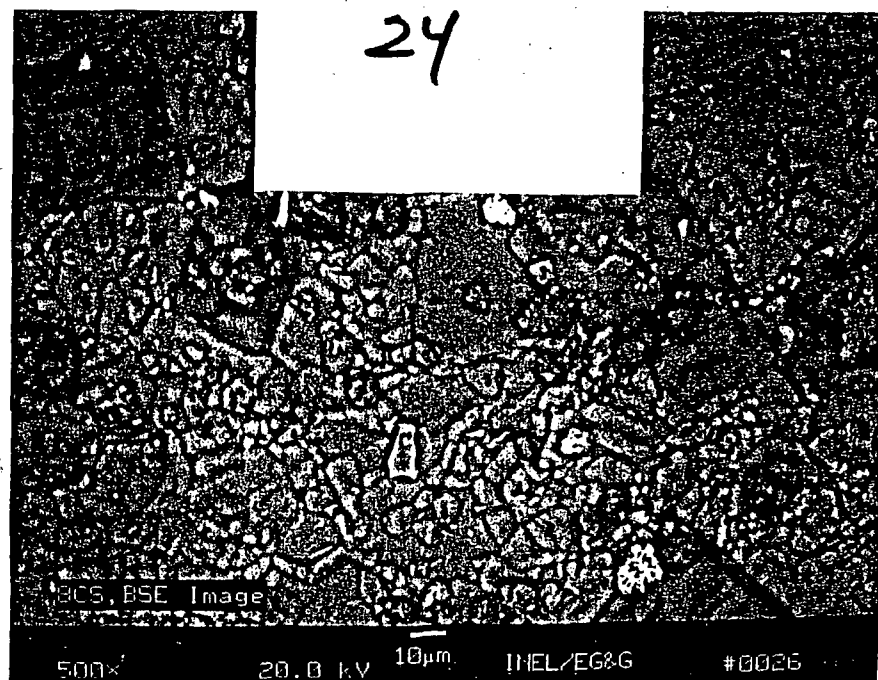
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PRELIMINARY DRAFT

BGS, BSE Image

100x 20.0 kV 100µm INEL/EG&G #0022

BGS, BSE Image

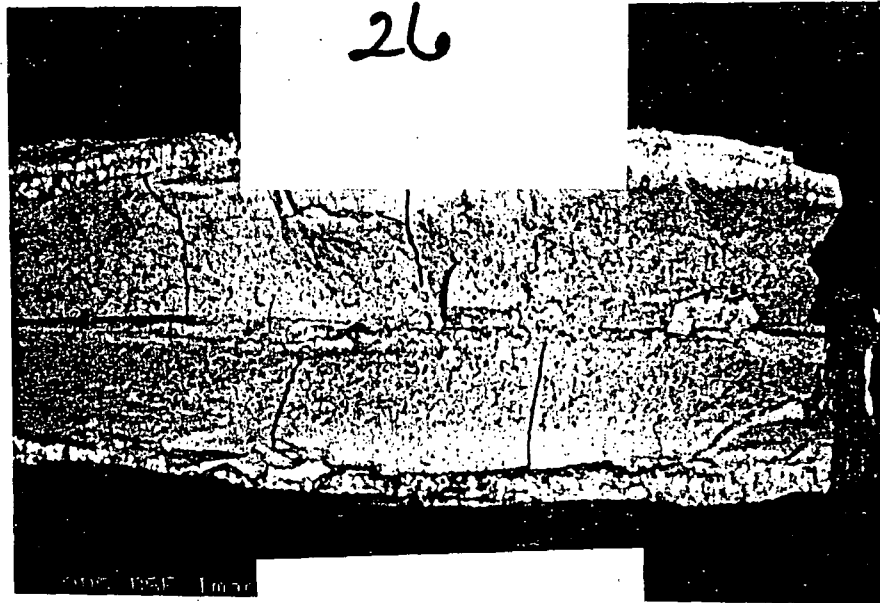
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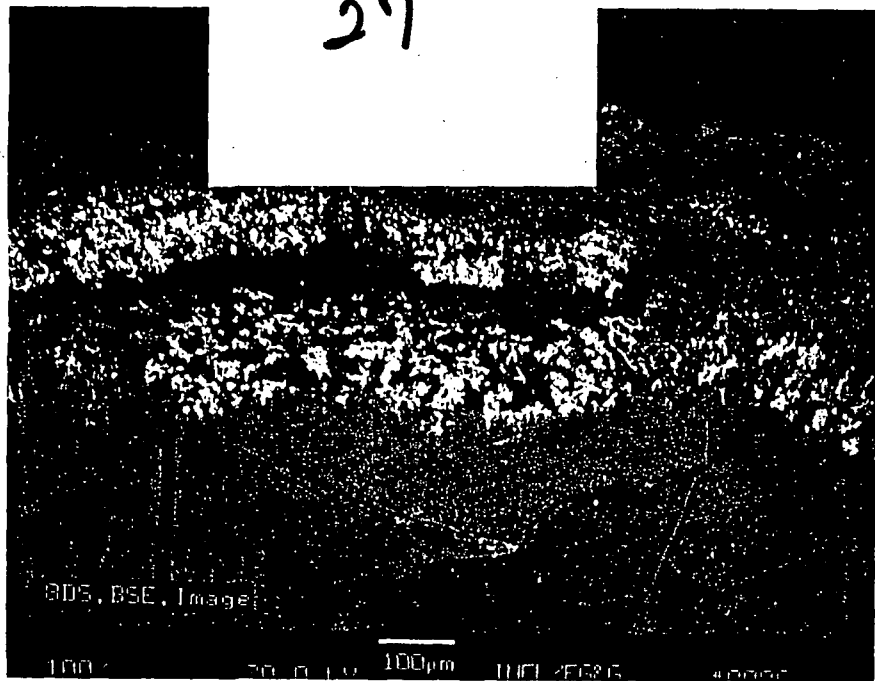


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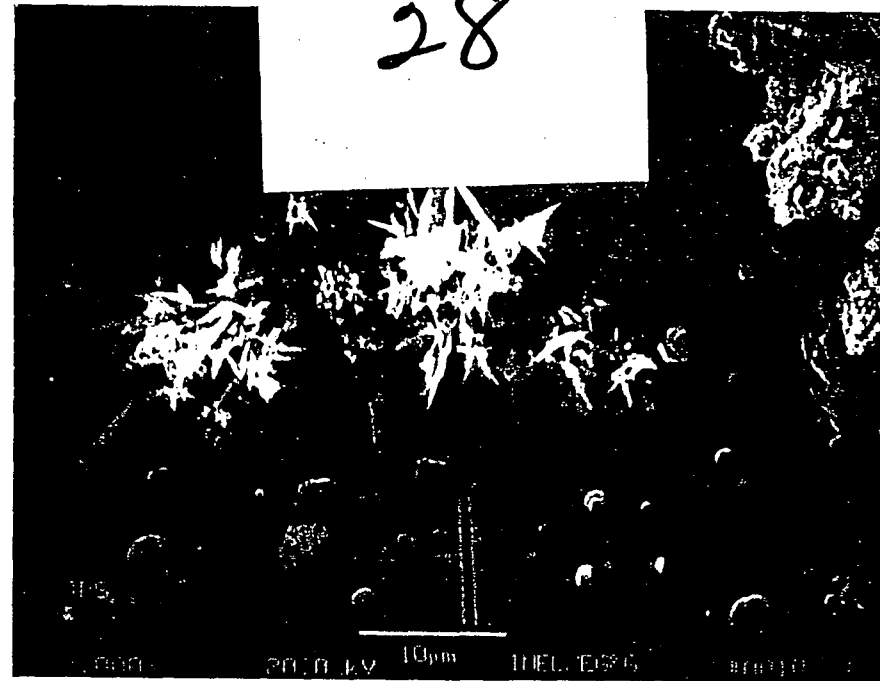
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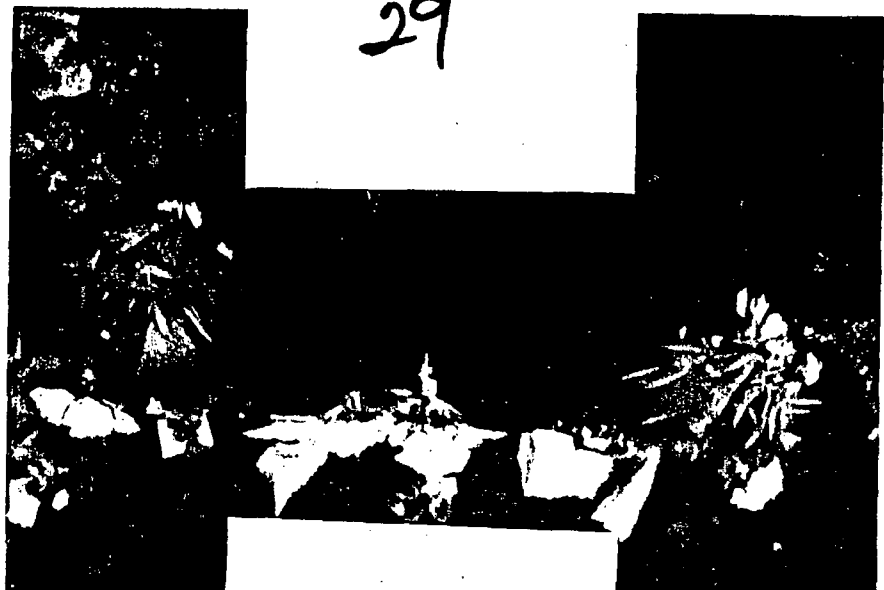
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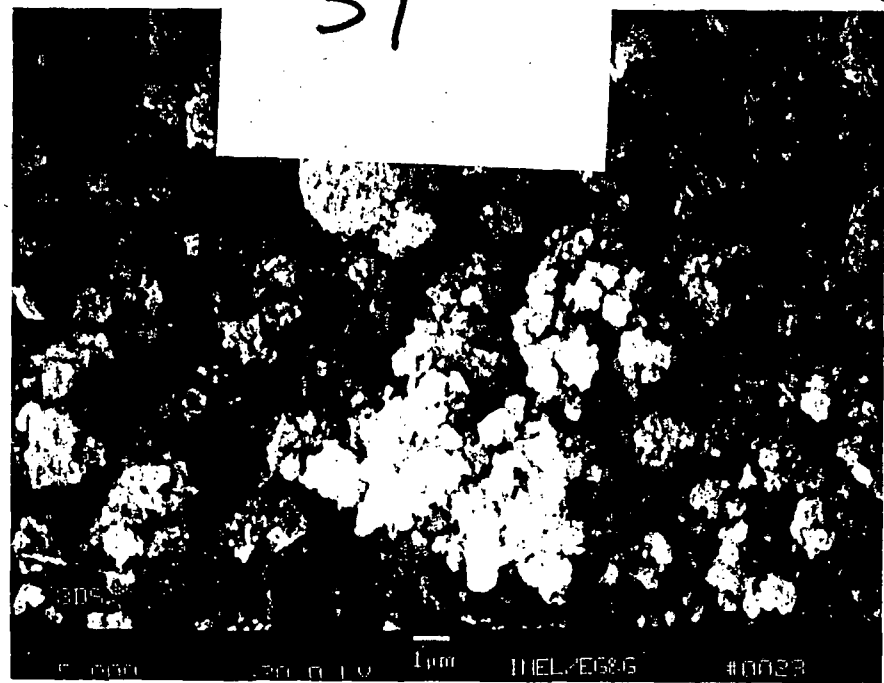
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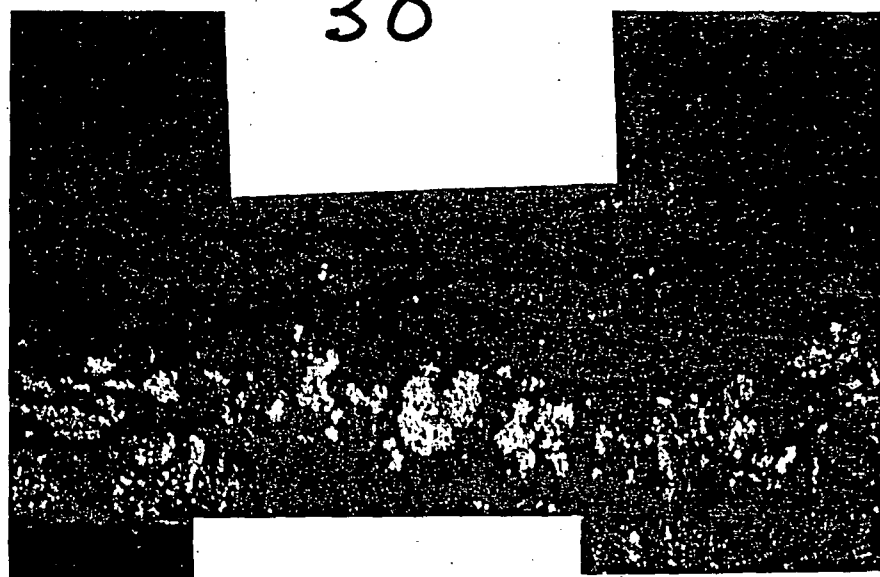
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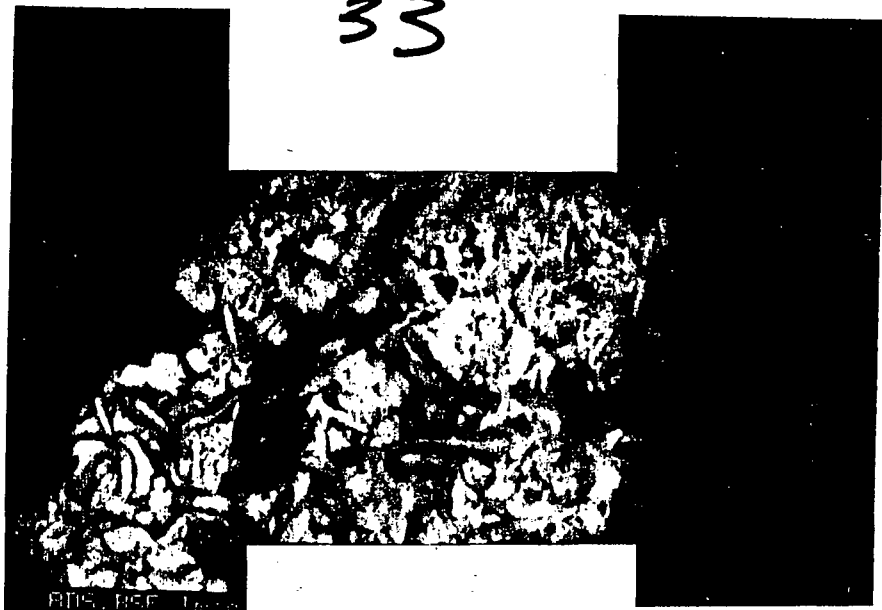


PRELIMINARY DRAFT

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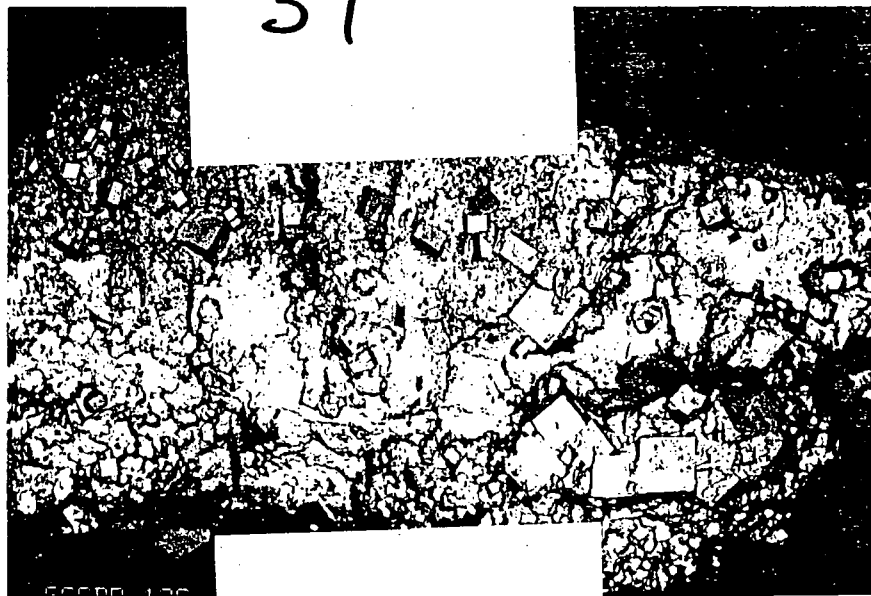
10µm

33



BSE Image

34



BSE Image

PRELIMINARY DRAFT

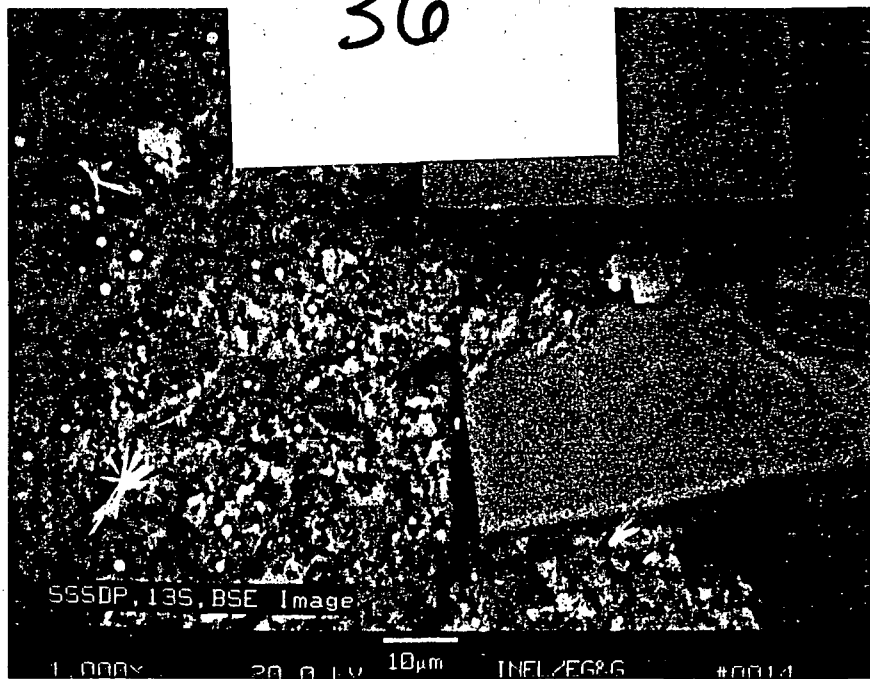
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SSDP, 135, BSE Image

500 20.0 kV 10µm INEL/EG&G #0009

36



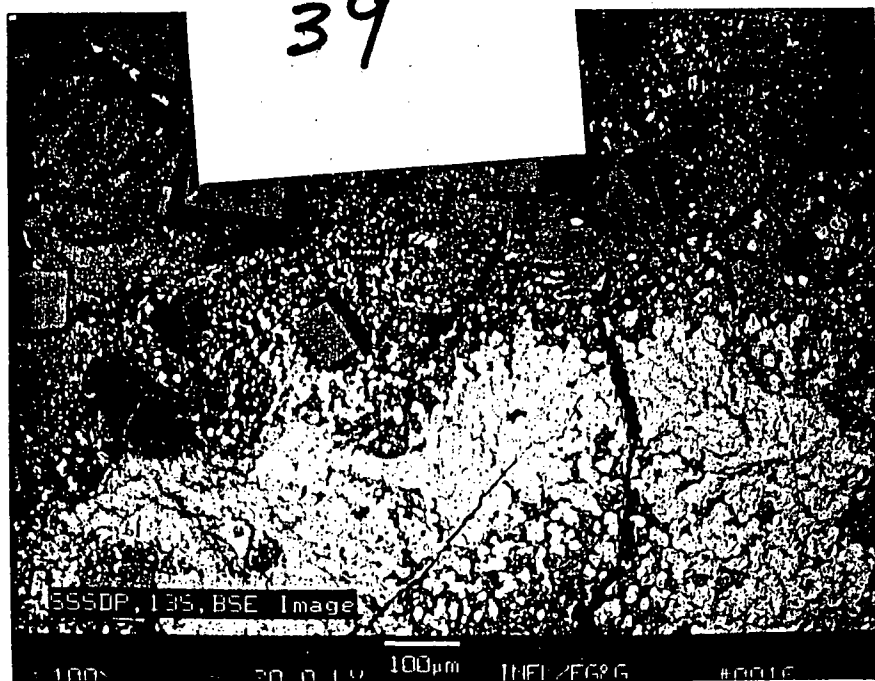
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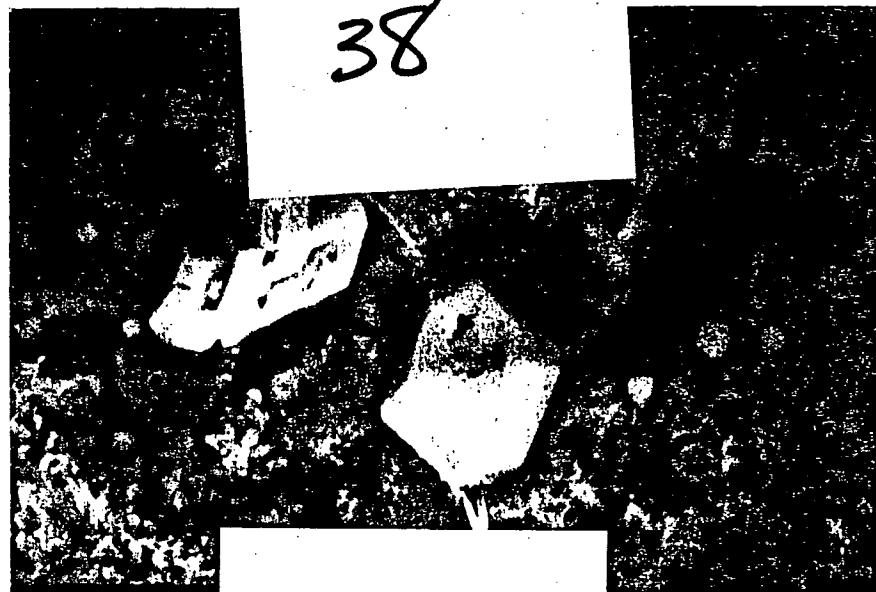
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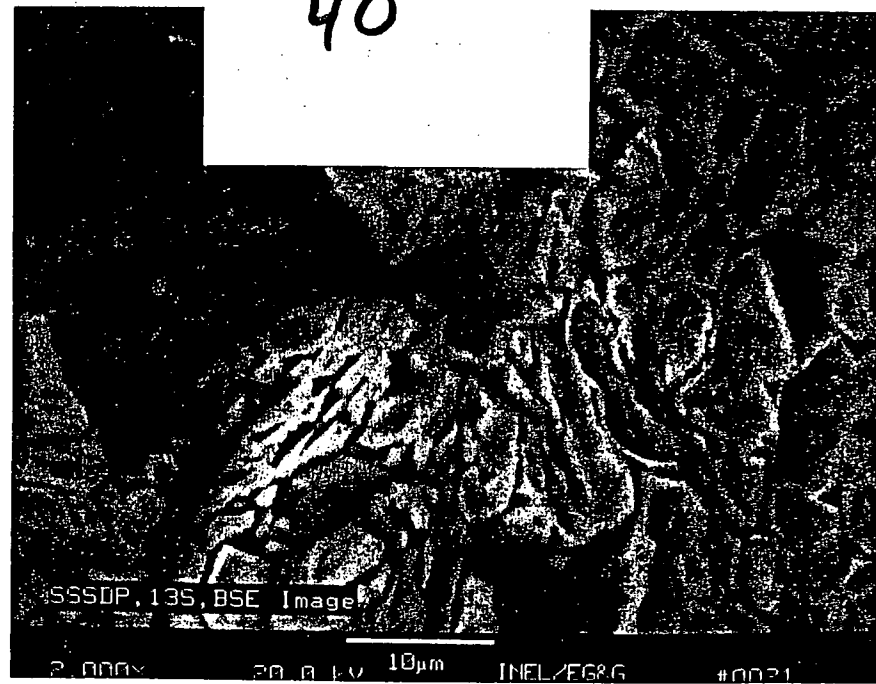
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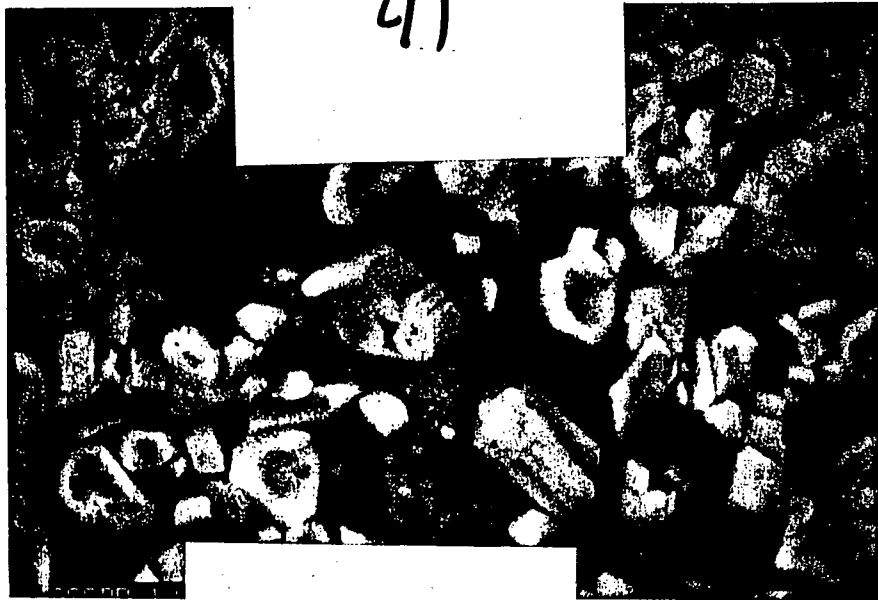


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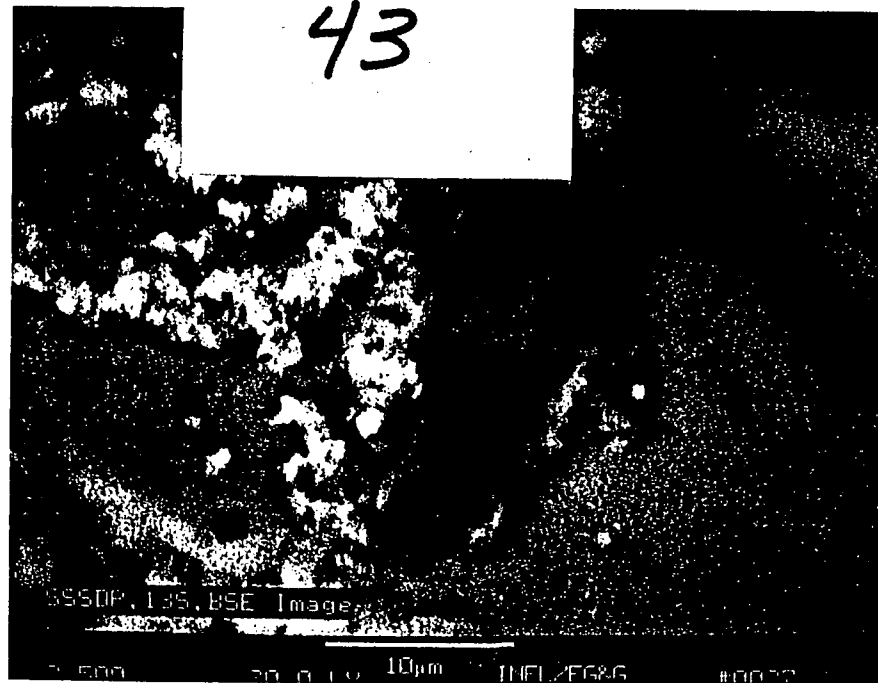


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PRELIMINARY DRAFT

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