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WP04691I

INTERIM REPORT (Jan. 6, 1978)

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SELECTED INVESTIGATIONS OF IGNEOUS DIKES INTRUDING OCHOAN SEDIMENTS IN THE CARLSBAD REGION

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SWCF-A: 1.4.3.3: NO-REPTS

INTRODUCTION

In this project we are examining the occurrence of near-verticle basaltic dikes and their effects on the Ochoan evaporite section in the Permian basin of southwestern New Mexico. The dikes are Tertiary in age and are observed in two somewhat disperate areas: poor surface exposures in the Yeso Hills some ten miles south-southwest of White City where the dikes intrude layered gypsum in the Castile Formation; and underground exposures in the Kerr-McGee potash mine (Kerr-McGee Hobbs Potash Facility) some 25 miles eastnortheast of Carlsbad where the dikes intrude the 10th ore zone of the Salado Formation.

Our principal objectives are to: (1) determine the thermal effects of the intrusions upon the host evaporite lithologies and their included silicate minerals; and (2) to provide chemico-mineralogic evidence toward answering the unresolved question as to whether the two distant occurrences represent a single extensive dike-complex or whether the two occurrences represent two distinct igneous events.

GEOLOGIC SETTING

Both exposures lie within the Permian basin of southeastern New Mexico and west Texas and the dikes are observed intruding the Ochoan evaporite strata. The dikes are characteristically thin (<5m), badly altered, nearly vertical, and have a general strike of N.45 - 60E. Trend projections from either locality can readily encompass the other.

The Yeso Hills occurrence

Numerous small, some even questionable, exposures of the dike as well as surface-stain accompanying float can be observed from southwest of the Red Top Tank (sec. 15, R.24E., T.26.S on the Carlsbad Caverns East 15' U.S.G.S. quadrangle) for nearly five miles to the northeast (sec. 31,

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R.25E., T.25S. on the same quadrangle). From the occurrence of float and iron-staining it appears that each individual dike is not extensive; but rather a family of parallel dikes are present with evidence of one to four thin dikes being encountered within a <200m traverse.

Two well-exposed occurrences of one individual dike was located which have provided the samples for the Yeso Hills dike study. These are located in two small NW trending canyons some 300 and 500 meters respectively north of the ranch road to Red Top Tank (near the center of the S 1/2 of sec. 11, T.26S., R.24E.). In both exposures the dike is ~2m thick with considerable variability of thickness at each outcropping; it contains distinct chilled margins, each ~3 cm wide, and an interior of spheroidal weathering drab dark green badly altered, somewhat friable rock. No evidence of severe alteration of the host bedded gypsum (Castile Formation) is evident. Surface stains and occasional pieces of altered basalt float on adjacent high ground between canyons suggest that sister dikes may well recur on either side of the exposed dike; however, no outcrops were seen up or down either canyon. This may be due to the extensive slumping, collapsing, and related movement and deformation of the bedded gypsum with resultant covering of the dike.

The exposed dike at both localities trends N.55E. and parallels the surface stain trends; a precise dip could not be measured because of the uneven and nonparallel character of its contacts with the gypsum. However, the altitude of the quasiparallel fractures in the dike and the "average" attitude of the contacts suggests a near-verticle dip.

It should also be noted that a range of textural variants can be observed in the float samples. Many contain small feldspar phenocrysts (<2m laths) while some contain no observable phenocrysts and some contain

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large (>15mm) laths. Colors range from rust-brown through dark grey to drab grey-green, and friability from crumbly or "finger-nail gougable" to tough and requiring a hammer for breaking; these latter properties reflect chiefly extent of alteration and recent weathering.

The Kerr-McGee occurrence

The Kerr-McGee mine exposure is located at a depth of 1530 ft. below the surface in sec. 31, T.20S., R.32E. just into Lea County. The dike was encountered along several drifts, many of which are no longer accessible; after recognizing that ore grade drops substantially to zero upon approaching the dike and because the mining equipment cannot satisfactorily penetrate the dike, no further operations to mine through or even to the dike are practiced.

The dike cuts the 10th ore zone in the mine; its relations to overlying and underlying strata cannot be seen. The 10th ore zone consists of a sylvite-halite ore with a rock salt unit at the base. At the location of the dike a salzton (mudstone) seam occurs at or near the floor; a second occurs at the top of the rock salt (~1m from the floor) and a third forms the drift back (~2m above the floor). Two dikes are present, the wider lies to the north and is ~4m wide with a strike of N.50°E.; the second occurs ~16m to the southeast with the same trend and is ~1.0m thick.

The altered basalt is dark-grey to black in color and substantially harder than that from the Yeso Hills. The extent of alteration is not recognizable in hand specimen. Commonly the basalt contains subspheroidal inclusions of clear halite from 0.1-2 cm in diameter; some of the halite "spheroids" include small crystals of anhydrite and/or magnesite.

The relations of the evaporite beds to the dike are pronounced. No changes are observed upon approaching the dike except for a very slight

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loss of reddish color beginning about 6-8m from the dike; all bedding features and integrety of the salzton seams persist without substantial modification. Varying from 5-20m from the wider (northern) dike and from 1-5m from the southern dike all features within the host rocks abruptly terminate and abut an envelope of variable thickness on both sides of the dike. This border zone or envelope is composed of massive, homogeneous, light-to-medium grey, transluscent halite with tightly intergrown crystals of variable size. The characteristic red color, the traces of bedding within the salts, and the thin salzton beds are completely absent. It is our conviction this represents a zone of melting of the evaporites and settling or inclusion into the igneous rock of unmolten debris (silicates, hematite, refractory evaporite salts).

The contact between the dike and the "fused salt envelope" is equally unusual. The dikes possess chilled margins some 2-5m thick but chilled margins which are brecciated into orthogonal slabs or "bricks" from 1-20 cm long and 0.1-4 cm thick. These bricks "float" in the fused salt matrix but generally remain subparallel and close to their parent dike. We think that molten salt penetrated the already solidified chilled margin via fractures and freed the "bricks" of chilled margin to form the unusual basalt-block briccia.

It is the sum of these features; i.e. the termination of the evaporite host textures, features, and nonsaline lithologies at the contact with the featureless, homogeneous, light grey halite envelopes, and the development of a "brickwork" breccia of basalt chilled margin blocks in a matrix of the featureless halite; which prompts our interpretation. Samples have been submitted to E. Roedder of the U.S.G.S. for fluid inclusion work on the salts.

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Our samples, their location with reference to distance south of arbitrary datum in the main haulage drift, their gross (handspeciman) lithology, and distance from the two dikes corrected for the nonorthogonality between the dike trend and the drift bearing are given in Table 1.

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TABLE 1

Location of samples of and adjacent to altered dikes, 10th ore zone, Kerr-McGee mine.

	Sample	Location* (m)	Lithology	Distance† (m) from North dike	Distance† (m) from South dike
1.	MB-76-20	0.0	Altered ore zone	1.0	--
2.	MB-76-22	0.9	Thin polyhalite dike	0.4	--
3.	MB-76-30	1.1	Thin clay seam	0.2	--
4.	MB-76-21	1.1	Altered ore zone	0.2	--
5.	MB-76-23	1.4	Altered dike basalt	--	--
6.	MB-76-24	1.8	Altered dike basalt	--	--
7.	MB-76-25	3.4	Halite lense in dike	--	--
8.	MB-76-26	6.4	Brecciated dike	--	6.8
9.	MB-76-28	6.6	Fused halite	0.1	6.7
10.	JT-77-3	~6.7	Ore zone	~0.2	~6.6
11.	MB-76-3	6.7	Altered ore zone	0.2	6.6
12.	MB-76-29	7.3	Rock salt	0.6	6.2
13.	MB-76-4	8.5	Altered ore zone	1.5	5.3
14.	MB-76-31	8.8	Clay and rock salt	1.7	5.1
15.	MB-76-32	8.8	Rock salt	1.7	5.1
16.	MB-76-33	12.2	Clay and rock salt	4.1	2.7
17.	MB-76-35	15.9	Rock salt	6.7	0.1
18.	MB-76-36	16.3	Altered dike basalt	7.0	--
19.	MB-76-34	16.6	Halite lense in dike	7.2	--
20.	MB-76-37	17.5	Altered ore zone	7.9	0.4
21.	MB-76-38	18.5	Rock salt	8.8	1.3
22.	MB-76-39	20.6	Rock salt	10.0	2.6
23.	MB-76-40	25.0	Rock salt	13.2	5.7
24.	MB-76-5	~30	Ore zone	~17	~8.5
25.	MB-76-41	30.5	Ore zone	17.0	8.8
26.	JT-77-5	~300	Ore zone	~300	~290

* Arbitrary datum in haulage drift.

† Distance normal to projected dike trend.

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SAMPLE PREPARATION AND ANALYSIS

Samples at both localities include representative dike specimens (not emphasized in this study as detailed petrography and petrology of the dike is being undertaken by the U.S.G.S. in Menlo Park) as well as suites of host rock extending from the dike contact outward into unaltered rocks.

Sample preparation

The igneous rock samples were slabbed to produce a slab for a conventional thin section. A split was crushed and ground to <200 mesh; then washed with distilled water to remove water-soluble salts; repeatedly centrifuged, decanted, and washed; and dried for diffraction and fluorescence study.

A split of each host rock sample was ground and crushed to <200 mesh; a split was retained for whole-rock analysis. The remainder was leached in water to dissolve water-soluble salts; repeatedly centrifuged, decanted, and washed in distilled water; then dried. A split was retained as the water-leached residue. The remainder was refluxed for four hours in boiling EDTA to dissolve the "acid-soluble" minerals, e.g. Ca-Mg carbonates, anhydrite, polyhalite, gypsum, following Bodine and Fernalld's (1973) procedure. The residue was again repeatedly centrifuged, decanted, washed; then dried and constituted the EDTA-leach residue. A split of this residue was retained as the whole EDTA-insoluble fraction; the remainder was sized into the >2μm and <2μm (effective spherical diameter) fraction by resuspending in distilled water, thoroughly disaggregating with an ultrasonic probe, and size fractionating using timed gravity sedimentation. Several of the samples were further fractionated into various micron and submicron fractions using timed centrifugation.

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In most cases, where sufficient samples were available, portions of the whole-rock, the water-insoluble, and the whole EDTA-insoluble fractions were pressed into pellets or "briquettes" for diffraction and fluorescence analysis. In addition, the <2μm fraction(s) were sedimented onto glass slides for x-ray diffractometer studies of oriented samples. These latter were investigated as an air-dried sample, an ethylene glycol saturated sample, and heated samples at 375°C and 500°C. Where insufficient sample was available for making a briquette we prepared a paste or smear mount on a glass slide.

Diffraction analysis

A conventional Norelco x-ray generator with a diffractometer and curved crystal monochromator was used throughout this study. We normally used a scanning speed of 2°2θ per minute and a chart speed of 1.0" per minute with Cu-radiation.

Fluorescence analysis

We analyzed for SiO_2, TiO_2, Al_2O_3, total Fe as Fe_2O_3, MnO, MgO, CaO, Na_2O, and K_2O with the Norelco Universal Vacuum X-ray Spectograph, Type 19010016 and Tennelec electronics with a TC214 amplifier and single channel analyzer, TC941 high-voltage bias supply, TC555P dual counter/timer, and a TC570 automatic recycle control and teletype interface; a Model 706 Kicksort channel pulse height analyzer aided in identifying appropriate energies for each element.

Counts for each element in each sample were recorded for two repetitions of the peak and associated background with a drift pellet run with each batch; counting statistics achieved a 1% standard deviation.

After averaging the recorded counts minus background to obtain net counts, we divided the sample net counts by the net counts of the drift

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pellet for the batch; this yielded net counts per drift and became the value which was correlated with concentration.

Similar procedures were also followed for the analyzed standards; these gave us net counts per drift as a function of concentration. Regression coefficients (least squares fit), calculated from net counts per drift vs. concentration, were fitted to the resultant curve and values of 0.990 - 0.999 were acceptable. These coefficients were considered acceptable when previously analyzed samples yielded XRF values within 3% of the known values.

Matrix effects (enhancement or depression of net counts for one element by another) were also considered. Staff of the N. M. Bureau of Mines and Mineral Resources (H. E. Marr, III, 1976 and J. E. Taggart, personal communication) have developed a computer program so that mass absorption corrections can be determined.

Standards used in this study include U.S.G.S. standards, some of our own clays analyzed by the N.M.B.M.M.R. and Herron Testing Laboratories, and weighed mixtures of chemical reagent salts; some of the latter were spiked with small amounts of analyzed silicate material.

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RESULTS

The general results acquired to date are presented below and compiled in Tables 2-7. Salt mineral identifications were determined routinely by x-ray diffraction and require no further discussion.

Chemical composition

Table 2 shows the composition of six dike samples, three from the Yeso Hills and three from the Kerr-McGee mine. The analyses are from salt-free samples and were determined by x-ray fluorescence using U.S.G.S. standards. The matrix effect calculations have not been completed; the reported data have been calculated using only the measured regression curves.

Table 4 includes the analytical data for all the major elements except SiO_2 and MnO in the EDTA-insoluble fraction from the Yeso Hills gypsums; these analyses were performed using the atomic absorption spectrometer because of the exceedingly low silicate mineral content, <0.1 g EDTA-insoluble residue/100 g whole rock. We are not particularly confident of their reliability and advise that the results be taken only as semi-quantitative values.

The x-ray fluorescence data for the EDTA-insoluble fraction of host rocks from the 10th ore zone in the Kerr-McGee mine are presented in Table 4; their proximity to the two dikes can be determined from Table 1. We have used similar clays analyzed by wet chemical methods and rapid silicate techniques as the standards. Again we have not yet calculated matrix effects and have used only our measured regression curves.

Even with these conditions we feel confident that the analytical data in Tables 2 and 4 are reliable. Since the standards use closely approximate the compositions if not always the mineralogy of our samples,

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TABLE 2

Chemical composition (wt. %) of altered basaltic dikes.

	MB-76-23	MB-76-24	MB-76-36	MB-76-45D	MB-76-45L	MB-76-46
SiO_2	50.1	49.1	49.8	48.2	48.5	48.2
TiO_2	2.3	2.4	2.2	2.4	3.0	2.7
Al_2O_3	14.4	13.8	14.4	13.5	13.3	13.1
Fe as Fe_2O_3	11.4	11.9	11.6	11.4	12.7	12.5
MnO	.18	.11	.15	.10	.08	.13
MgO	7.3	8.3	7.7	4.4	4.4	4.1
CaO	2.7	3.7	3.1	6.7	5.0	6.1
Na_2O	2.1	2.8	2.3	3.9	3.5	4.5
K_2O	8.0	5.3	6.9	2.9	2.8	3.1
Total*	98.5	97.4	98.2	93.5	93.3	94.4

* Does not include H_2O (+105°C).

MG-76-23: Brecciated chilled margin of north dike, Kerr-McGee mine cutting 10th ore zone.

MB-76-24: 0.4m from north contact of north dike, Kerr-McGee mine cutting 10th ore zone.

MB-76-36: 0.6m from north contact of south dike, Kerr-McGee mine cutting 10th ore zone.

MB-76-45D: Dark grey facies within dike intruding Castile Formation, Yeso Hills.

MB-76-45L: Medium grey facies within dike intruding Castile Formation, Yeso Hills.

MB-76-46: Chilled margin (southeast) of dike intruding Castile Formation.

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TABLE 3

Composition and mineralogy of EDTA-insoluble residues in Castile Formation samples adjacent to well exposed altered basaltic dike in the Yeso Hills.

	MB-76-47	MB-76-48	MB-76-49	MB-76-50	MB-76-51
Lithology	Banded gypsum	Banded gypsum	Banded gypsum	Banded gypsum	Banded gypsum
Distance from dike (meters)	0.0	0.0	0.5	1.5	12.0
Weight percent					
TiO_2	1.15	1.50	.99	1.00	1.03
Al_2O_3	10.8	12.1	14.0	6.09	12.7
Fe as Fe_2O_3	2.19	3.92	2.61	1.96	2.61
MgO	5.07	8.31	.52	6.08	2.23
CaO	.43	.66	.27	4.39	.32
Na_2O	7.65	8.21	7.64	2.43	5.54
K_2O	1.07	1.16	3.14	2.34	1.82
Atom proportions (Al = 1.00)					
Ti	.068	.079	.045	.10	.052
Al	1.00	1.00	1.00	1.00	1.00
Fe	.13	.21	.12	.21	.13
Mg	.60	.87	.047	1.26	.22
Ca	.036	.050	.018	.66	.023
Na	1.17	1.12	.90	.66	.72
K	.11	.10	.24	.42	.16
Mineralogy					
Quartz	XX	X	x	XX	XX
Plagioclase	X	XX	XX	x	X
Hydrobiotite (?)	x	XX	a	x	--
Illite	--	--	a	a	a
Pyrite	a	a	a	--	--
Dolomite	--	--	--	XX	--

Mineral abundances: XX = dominant; X = major; x = minor; a = accessory; -- = not detected.

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TABLE 4

Chemical compositions (wt. %) and atom proportions (Al = 1.00) of EDTA-insoluble residues in Kerr-McGee 10th ore zone evaporites (cont'd).

	MB-76-35	MB-76-34	MB-76-37	MB-76-38	MB-76-39	MB-76-40	MB-76-5	MB-76-41	JT-76-5
Weight percent									
SiO_2	44.7	44.0	47.0	46.6	45.5	44.2	46.8	45.8	45.2
TiO_2	.45	.58	*n.d.*	.62	.72	.61	.62	.69	.67
Al_2O_3	9.03	11.5	9.81	11.2	10.5	11.4	11.2	11.1	10.1
Fe as Fe_2O_3	2.17	4.87	*n.d.*	3.81	3.00	4.07	3.96	3.38	5.05
MnO	.017	.028	.010	.029	.034	.033	.028	.033	.043
MgO	25.2	26.6	28.8	25.7	26.3	26.9	25.9	26.8	25.9
CaO	.001	.011	--	.003	<.001	.005	.050	.005	.007
Na_2O	1.53	1.29	1.38	1.23	1.03	1.13	1.19	1.26	.910
K_2O	3.76	1.49	6.32	1.74	1.34	1.62	1.37	1.70	1.43
Total	86.9	90.4	93.3	90.9	88.4	90.0	91.1	90.8	89.3
Atom proportions (Al = 1.00)									
Si	4.20	3.25	4.06	3.54	3.69	3.30	3.55	3.49	3.80
Ti	.032	.032	*n.d.*	.035	.044	.034	.035	.040	.042
Al	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fe	.15	.27	*n.d.*	.22	.18	.23	.23	.19	.32
Mn	.0014	.0018	.0007	.0019	.0023	.0021	.0018	.0021	.0031
Mg	3.53	2.92	3.71	2.91	3.18	3.00	2.93	3.04	3.24
Ca	.0001	.0009	--	.0002	<.0001	.0004	.0041	.0004	.0006
Na	.28	.18	.23	.18	.16	.16	.17	.19	.15
K	.45	.14	.70	.17	.14	.15	.13	.17	.15

-- = not detected; *n.d.* = not determined.

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TABLE 4 (cont'd)

Chemical compositions (wt. %) and atom proportions (Al = 1.00) of EDTA-insoluble residues in Kerr-McGee 10th ore zone evaporites.

	MB-76-22	MB-76-30	MB-76-21	JT-77-3	MB-76-3	MB-76-29	MB-76-4	MB-76-32	MB-76-33
Weight percent									
SiO_2	44.5	45.5	45.9	45.3	46.1	46.5	46.4	43.7	48.2
TiO_2	.56	.65	.61	.53	.59	.53	.60	.50	.65
Al_2O_3	11.4	11.8	12.2	11.5	12.6	10.9	10.7	9.58	10.9
Fe as Fe_2O_3	3.14	1.45	1.42	1.85	1.04	.88	1.75	2.60	2.92
MnO	.007	.014	.019	.021	.009	.011	.020	.031	.024
MgO	29.2	28.8	27.4	29.7	29.6	29.0	25.8	28.0	25.3
CaO	.003	.012	.014	.008	--	--	--	.010	.007
Na_2O	.39	1.18	1.85	.55	.92	1.20	1.85	1.25	1.10
K_2O	8.86	7.82	7.10	8.7	8.04	7.95	4.40	1.40	1.90
Total	98.1	97.2	96.5	98.2	98.9	97.0	91.5	87.1	91.0
Atom proportions (Al = 1.00)									
Si	3.2	3.3	3.2	3.35	3.11	3.62	3.68	3.87	3.75
Ti	.032	.035	.032	.030	.030	.031	.036	.033	.038
Al	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fe	.18	.079	.074	.10	.053	.052	.10	.17	.17
Mn	.0004	.0009	.0011	.0013	.0005	.0007	.0013	.0023	.0016
Mg	3.26	3.10	2.83	3.28	2.97	3.37	3.06	3.70	2.93
Ca	.0002	.0009	.010	.0006	--	--	--	.0009	.0006
Na	.057	.17	.25	.079	.12	.18	.29	.21	.17
K	.84	.72	.63	.82	.69	.79	.45	.16	.19

-- = not detected; *n.d.* = not determined.

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the errors introduced by matrix variation should be minimal. We are substantially less confident of the chemical data in Table 3 and will use it cautiously in our discussion.

Silicate mineralogy

Identification of the minerals constituting the EDTA-insoluble fraction relies heavily on x-ray diffraction data, correlation with the sample's chemical composition, and, to a much lesser extent, upon microscopic properties. Illustrative x-ray diffraction traces of significant features are given in Appendix I.

Quartz and feldspar

These common phases are readily identified in diffraction patterns; however, in those samples containing only minor quantities of feldspar it was not often possible to assign composition to the feldspar. Only where the feldspar $20\bar{1}$ reflection is descernible and can be differentiated from the 100 peak of quartz could we determine plagioclase vs. K-feldspar: $d_{20\bar{1}}$(K-feldspar) = ~4.25Å; $d_{20\bar{1}}$(plagioclase) = ~4.03Å.

Biotite

Biotite is confined to the altered basalt and occurs in the featureless altered groundmass of fine-grained fledspar and other hydrous phyllasilicates. It is recognized by its dark color, pliochroism, and parallel extinction; it was verified by x-ray diffraction.

Chlorite and clay chlorite

Chlorite occurs as an alteration mineral in the basalt and as a clay mineral in the host evaporites and salztons. It can be recognized by x-ray diffraction with the 14Å basal spacing periodicity which is not altered by glycol saturation.

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Illite

Illite occurs as an important clay constituent in the evaporite rocks and associated salztons. The mineral is readily identified by its characteristic 10Å basal spacing reflections and 060 reflection. In both localities there appears to be some but not substantial random smectite interlayering.

Talc

Talc occurs in the Kerr-McGee ore zone evaporites and associated salztons; it is readily recognized in x-ray diffraction patterns of oriented silicate residues. Talc's strong, sharp diffraction maxima at 9.5 and 3.14Å, d_{001} and d_{003} respectively, are distinctive.

Trioctillite (a new trioctahedral mica clay mineral)

We believe that the phologapite-like trioctahedral analog to the dioctahedral mica clay illite is sufficiently distinctive, both mineralogically and genetically, to warrent new mineral status. The mineral occurs in the 10th ore zone evaporites near the dike contact in the Kerr-McGee mine. We are proposing the name trioctillite for this phase and will summarize its properties in a subsequent section.

Expandable clays

Smectite-bearing clays fall principally into three groups: (a) saponite, (b) randomly interstratified mixed-layer chlorite-smectite, and (c) regularly interstratified mixed-layer chlorite-smectite (corrensite). Saponite is characterized by expansion of the ~14Å peak to 16-17Å upon glycol saturation, the mixed-layer chlorite-saponite by expansion only to 15.5Å. The regular interstratified chlorite-smectite clay (corrensite) is characterized by having a well developed superlattice reflection of ~28-29Å which expands to >30Å upon glycolation.

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Initially we were puzzled by the abundance of a strong 11.5-12.5Å reflection in many air-dried samples. Upon glycolation this reflection expanded from 15.5-17.0Å. The latter suggest the reflections are due to a saponite or smectite-chlorite mixed layer phase; however, the air-dried spacings were far too low. If the air-dried material with its anomalously low reflection, e.g. sample MB-76-37 with a strong maximum at 12.3Å, is suspended in 1M NaCl or $MgCl_2$ solutions, then washed, mounted, and air-dried, the strong maximum occurs at 14.4 and 14.8Å respectively. Upon glycolation both the NaCl and $MgCl_2$ treated samples expanded to 16.7Å. We suggest that the EDTA-treatment resulted in partial stripping of the interlayer material and collapse to the 12.3Å spacing with characteristic spacings, 14-15Å and expansion to 16-17Å, restored by appropriate treatment with Na^+/Mg^{+2} or ethylene glycol respectively.

Another mineral, restricted to banded gypsum adjacent to the dike at the Yeso Hills locality, we have tentatively identified as hydrobiotite, a mixed layer mica-clay and vermiculite/saponite. Its air-dried 11.8-12.4Å peak does not return to a 14Å spacing upon NaCl or $MgCl_2$ treatment; it expands only slightly to ~12.6Å upon glycol saturation. Thus, it conforms to the data for hydrobiotite given by Thorez (1975).

Chemical analyses

Compositions of the altered dike at our two localities are reported in Table 2; those of the EDTA-insoluble fraction of gypsums associated with the dike intrusions at Yeso Hills in Table 3; and those of the EDTA-insoluble fraction of the 10th ore zone salts in the Kerr-McGee mine in Table 4. Again we should point out that the analyses of Table 3 are from atomic absorption spectrometer determinations on very small samples; we are not overly confident of the accuracy of the results and suggest they

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be considered only semiquantitative.

The evaporite silicate residues have been recast to atom proportions with Al = 1.00 (Tables 3 and 4). In Table 3 the difficulties with this group of analytical results are apparent; $\Sigma Na + K > 1$ in most cases which is impossible to correlate with a feldspar-clay assemblage.

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TRIOCTILLITE -- A NEW MICA-CLAY MINERAL

An alteration product in the ore zone salts and salztons associated with the intrusions in the Kerr-McGee mine is a trioctahedral mica clay. Its chemical and structural similarity to its megascopic analog phlogopite is essentially identical to that observed between illite and its megascopic analog muscovite. For this reason we are proposing the name trioctillite in reference to its being a trioctahedral illite.

We suggest this material be considered a clay mineral. Size fractionation after ultrasonic disaggregation yields 68% of EDTA-insoluble fraction within the <2μm fraction; the pronounced abundance of this mica clay at ~8.7 and 26.5°2θ throughout the several size ranges is readily apparent in Fig. 1.

X-ray diffraction properties

Trioctallite's basal reflections (Fig. 1) are entirely compatible with its definition as a trioctahedral mica-clay:

d_{001} = 10.13Å
d_{002} = 5.082
d_{003} = 2.531
d_{004} = 2.029
d_{060} = 1.536

The basal spacings which are slightly larger than for the dioctahedral mica clays suggest a trioctahedral; the large value for the 060 reflection confirms this. Unfortunately we are as yet unable to discuss its polytypism as per Smith and Yoder (1956) and Yoder and Engster (1954) because of the weakness of hk0 reflections. As would be expected no change in these reflections occurs with either glycol saturation or heat treatments.

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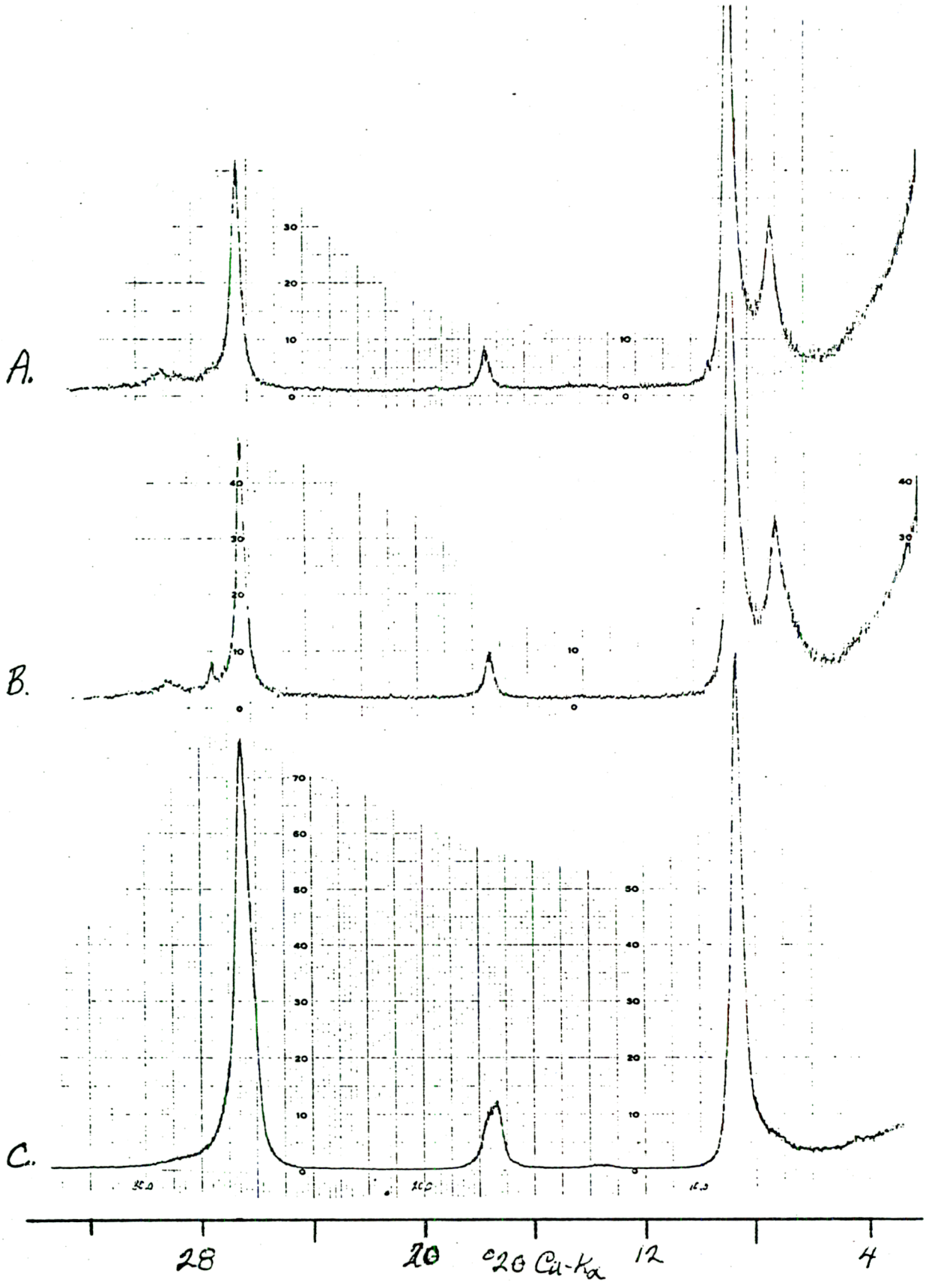

Figure 1. Three size-fractions of the EDTA-insoluble residue of MB-76-3 showing the dominance of trioctillite throughout the sample.

A. 8-2μm (effective spherical diameter) fraction.
B. 2-0.5μm (effective spherical diameter) fraction.
C. <0.12μm (effective spherical diameter) fraction.

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Chemical composition

The chemical analysis of whole EDTA-insoluble fraction is best given in Table 4 for MB-76-3; this sample is as close to a monomineralic trioctillite as we presently have. As can be seen from Table 6 and Fig. 1 there are very small contaminating amounts of quartz and a chlorite-saponite mixed-layer clay. However, for the purposes of this discussion we will assume the trioctillite composition is close to that obtained from the analysis. In Table 6 we show the analysis recast to 22 negative charges as befits the anhydrous mica structural formula,

$$K\ Mg_3\ (AlSi_3)\ O_{10}\ (O) \quad .$$

The recast analysis (Table 5) fits exceedingly well into the mica structural formula. We suggest the low interlayer site occupancy (0.8 instead of 1.0) is to be expected since almost all illites exhibit this or greater interlayer difficiency (Weaver and Pollard, 1973).

Discussion

Trioctahedral illites have previously been reported (Walker, 1950 and Weiss et al., 1956). However, the former, believed them to be authegenic, altering to a vermiculite so rapidly that unweathered material is difficult to separate; the latter is a very brief with unconvincing evidence as to its validity.

We propose that this material be designated the new mineral species trioctillite. Its convincingly unique clay-size mode of occurrence and its interlayer cation deficiency differentiate it from phlogopite; its trioctahedral structural formula as well as chemical composition differentiate it from illite, seircite, glauconite, and other accepted mica clays.

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TABLE 5

Chemical analysis of MB-76-3 EDTA-insoluble fraction, essentially trioctillite with minor chlorite-saponite mixed-layer clay, recast to atom proportions in the anhydrous form of the phlogopite structural formula.

		Atoms per 11 O's	
Tetrahedral:			
	Si	3.04	
	Al	.96	
	Total		4.00
Octahedral:			
	Al	.02	
	Ti	< .01	
	Fe	.05	
	Mg	2.91	
	Total		2.99
Interlayer:			
	Ca	<< .01	
	Na	.12	
	K	.68	
	Total		.80

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DISCUSSION AND INTERPRETATION

Intrusive rocks

At this time we are moderately confident that the two occurrences, one in the Yeso Hills and the other in the Kerr-McGee mine, belong to the same igneous event and represent a single family of intrusives forming an extended linear feature.

The trend projection from one locality to the other is supportative of this conclusion; the geophysical and geologic data reported to Sandia by Elliott (1976) further support this view.

Our chemico-mineralogic evidence supporting this conclusion is not overwhelming. We note that the dike is severely altered with chloritized-argillitized mafic minerals. Therefore, since the two host rocks are distinctly different (K-salts, halite vs. gypsum, calcite) and promote two significantly different sets of alteration mineralogy (Table 6) and chemical composition (Table 2).

We do note, however, that while the atom ratios of more mobile constituents (Mg/Ca and K/Na) are strikingly different between the two localities (Table 6). [Mobile constituents in this discussion refer to those elements which can be expected to move relatively freely by aqueous transport.] As will be discussed in the next section, the variation in the ratios of mobile constituents between the two localities are compatible with exchange reactions between the host rock and the intrusion. The atom ratios involving the less mobile components (Ti/Al, Fe/Al, and Mn/Al) do remain relatively constant with no significant difference between the two localities. Thus our evidence is equivocal; it neither strongly supports the hypothesis of a single igneous episode nor does it cast serious doubt on the hypothesis.

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TABLE 6

Comparison and contrast of Kerr-McGee Mine and Yeso Hills dike rocks.

	Kerr-McGee			Yeso Hills		
	MB-76-23	MB-76-24	MB-76-36	MB-76-45L	MB-76-45D	MB-76-46
Atom proportions						
Ti/Al	.10	.11	.10	.12	.14	.13
Fe/Al	.51	.55	.51	.54	.61	.61
Mn/Al	.009	.006	.008	.005	.004	.007
Mg/Ca	3.8	3.1	3.4	.91	1.21	.94
K/Na	2.5	1.2	2.0	.49	.51	.46
Mineralogy*						
K-feldspar	X	x	X	x	x	x
Plagioclase	X	X	X	XX	XX	XX
Biotite	X	X	X	x	a	x
Chlorite	a	x	x	--	--	x
Smectite	--	--	--	X	X	--
Opaques+	X	X	X	x	X	X

* Relative abundances from diffraction maxima intensities: XX = dominant; X = major; x = minor; a = accessory; -- = not detected.

\+ Includes magnetite, hematite, ilmenite, and pyrite.

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Host rock alteration

The host rocks at both localities do exhibit alteration halos surrounding the intrusion; these are more strongly developed at the Kerr-McGee locality than in the Yeso Hills

Yeso Hills

The small amount of the EDTA-insoluble fraction in Yeso Hills gypsums has hindered our investigations but yet some changes in the silicate residue as a function of distance are present.

Textural and nonsilicate mineralogic changes are not apparent except that MB-76-50 (1.5m from the dike) does contain dolomite; whether the dolomite is related to intrusion or not is unknown. The absence of textural changes, however, does indicate that the host rock was undoubtedly anhydrite at the time of intrusion; were it gypsum a wide variety of textural/fabric/structural effects should have been preserved reflecting localized gypsum dehydration. The thinly (<0.5 cm) to thickly (>5m) banded character of the gypsum is neither destroyed nor noticably deformed upon approaching the dike.

The silicate assemblage in the gypsum indicates crystallization of (?) hydrobiotite and additional plagioclase (albite) adjacent to the dike with a corresponding loss of illite (Table 3). Chemically this is reflected by the increase of Na/K, Mg/Ca, and (Na + K + 2Mg)/Al upon approaching the dike (Table 3). More work is essential toward defining the alteration phenomena in the gypsum beds in the Yeso Hills.

Kerr-McGee mine

The 10th ore zone reveals extensive changes in the host rock as the result of the dike intrusion; these changes are reflected both in the salt assemblages and in the silicate assemblages included in the salts and in

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discrete salzton beds (Table 7).

The fused salt margins, enveloping the dikes, consist of essentially pure halite; MB-76-28, for example, contains 37.1 wt. % Na with 0.24, 0.15, and <0.01 wt. % Ca, Mg, and K respectively in the whole rock. The EDTA-insoluble residue content in fused salt margins is negligible (<<1 wt. %).

The salts within the ore zone itself have been altered adjacent to the ore zone; thus, sylvite is essentially absent within 8 meters of the north (thick) dike and reasonable ore grade is not found within <12m of the north dike and <5m from the south dike. In addition, we also note that where high potash content does occur in the salts close to the dike it is present as polyhalite, e.g. MB-76-22 a thin polyhalite "stringer" dike close to the intrusion with 13.0 wt. % K, and MB-76-27, altered ore zone adjacent to the fused salt envelope, with 6.52 wt. % K.

Although the evaporite salts underwent extensive alteration adjacent to the dike there are, as at Yeso Hills, only minimal textural effects observed outside the fused salt envelop; bedding, features due to variation of clay inclusion content, extent of red coloration, and salt crystal fabric and textures, are not disturbed. Without a hand lense, or in many cases without chemical analysis, the ore still looks like ore, and the barren halite and salzton beds remain unchanged. Essentially the salt recrystallization process represents a grain replacement phenomenon rather than massive dissolution and recrystallization.

The silicate minerals in the EDTA-insoluble fraction also show marked variation in respose to the dike intrusion. The alteration pattern essentially follows the following path (Fig. 2):

(1) An unaltered assemblage of a regularly interstratified mixed-layer chlorite-saponite (corrensite), dioctahedral mica clay

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TABLE 7

Relative mineral abundances in evaporite strata of 10th ore zone related to basaltic dike.

	Whole Rock						EDTA-insoluble fraction					
	Hal	Syl	Poly	Anhy	Mag	Sil	Phl	Ill	Talc	Qtz	Exp	Ch
MB-76-20	XX	--	x	--	--	a	*negligible silicate*					
MB-76-22	X	--	XX	x	X	x	X	—	--	--	—	--
MB-76-30	X	--	x	--	a	XX	XX	--	--	--	X_{ch-sm}	--
MB-76-21	XX	--	x	--	x	x	XX	—	--	X	--	--
MB-76-27	XX	--	X	--	--	x	XX	--	--	--	XX_{sm}	--
MB-76-28	XX	--	x	--	a	x	XX	--	—	--	x_{sm}	--
JT-77-3	X	--	x	--	--	XX	XX	--	--	X	--	--
MB-76-3	XX	--	x	--	--	X	XX	--	--	a	x_{ch-sm}	--
MB-76-29	XX	--	x	--	x	x	XX	--	--	--	x_{ch-sm}	—
MB-76-4	XX	--	x	--	--	X	X	--	X	--	XX_{ch-sm}	--
MB-76-31	XX	--	a	--	X	X	X	--	x	X	XX_{sm}	a
MB-76-32	XX	--	--	--	X	x	?	X	X	X	XX_{ch-sm}	x
MB-76-33	XX	--	a	--	x	X	--	XX	XX	—	X_{ch-sm}	x
MB-76-35	XX	--	--	--	X	x	--	X	XX	--	XX_{ch-sm}	x
MB-76-34	XX	--	--	x	a	a	*negligible silicate*					
MB-76-34D	XX	a	--	--	x	x	--	X	—	--	XX_{ch-sm}	x
MB-76-37	XX	x	X	a	x	X	XX	--	--	--	--	--
MB-76-38	XX	--	--	--	x	x	--	X	X	XX	XX_{ch-sm}	x
MB-76-39	XX	a	--	--	x	x	--	XX	X	--	XX_{ch-sm}	x
MB-76-40	XX	x	--	—	X	x	--	X	x	—	XX_{ch-sm}	x
MB-76-5	XX	X	--	--	x	X	--	X	x	--	XX_{ch-sm}	x
MB-76-41	XX	x	--	--	a	x	--	XX	x	--	XX_{ch-sm}	x
JT-77-5	X	--	--	--	--	XX	--	X	—	X	XX_{ch-sm}	x

Mineral abundances: XX = dominant; X = major; x = minor; a = accessory; -- = not detectable.

Mineral symbols: Hal = halite; Syl = sylvite; Poly = polyhalite; anhy = anhydrite; Mag = magnesite; Sil = silicates; Phl = trioctahedral mica clay; Ill = illite; Qtz = quartz; Exp = expandable clays with subscripts ch-sm = interlayered saponite and chlorite, and sm = smectite; ch = chlorite.

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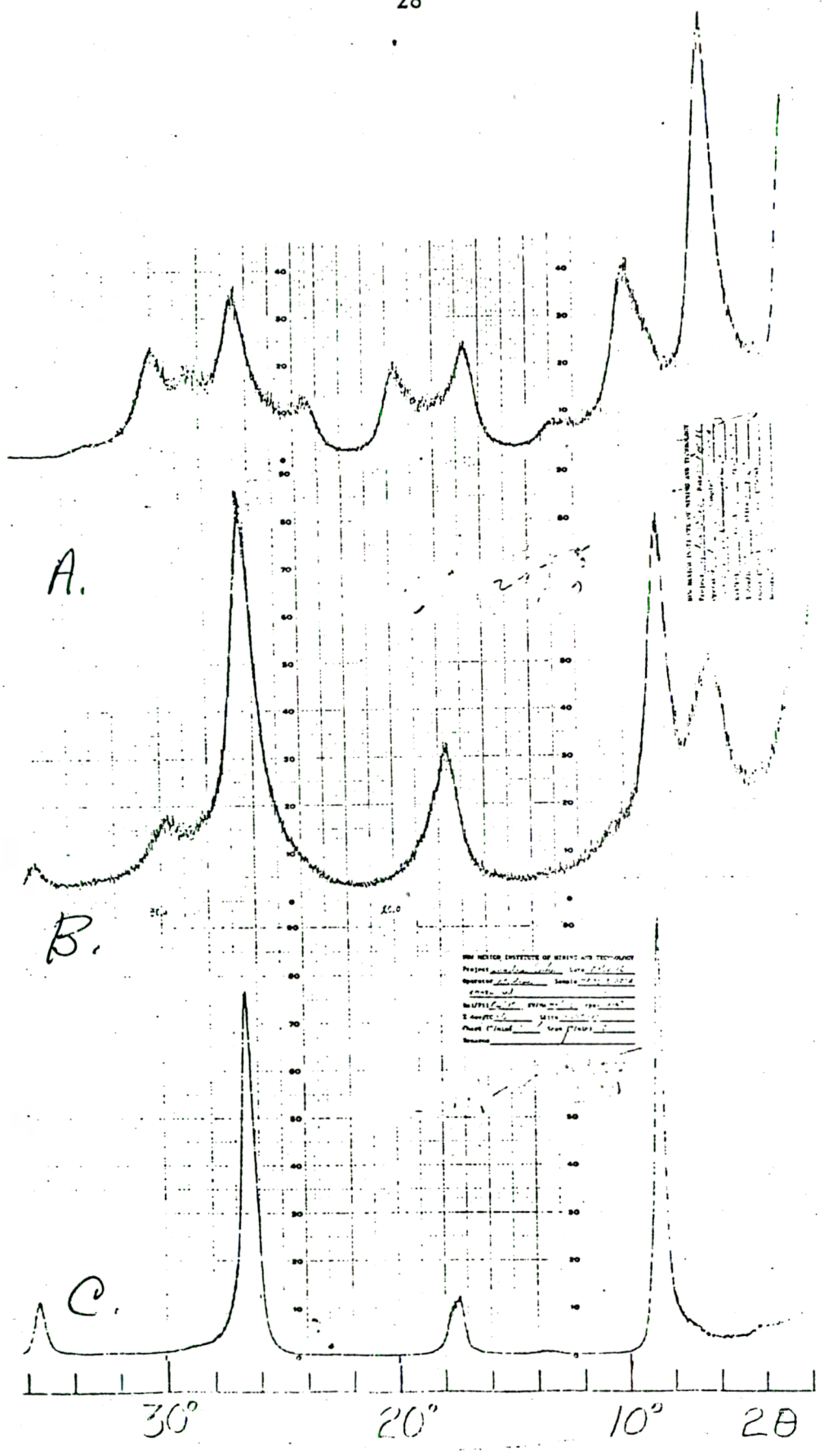

Figure 2. The 0.12 m (effective spherical diameter) size-fractions of the EDTA-insoluble residues; size sufficiently fine to exclude talc and most dioctahedral illite, both are present in coarser fractions of A and B.

A. MB-76-5: unaltered regularly interstratified clay.
B. MB-76-4: partially altered randomly interstratified clay and illite.
C. MB-76-3: almost completely altered to trioctilllite.

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(illite) talc, and subsidiary chlorite as represented by MB-76-5.

(2) A partially altered randomly interstratified mixed layer chlorite-saponite (with interlayer cations stripped by EDTA-treatment), poorly crystallized mixed-layer illite-saponite, and well crystallized talc and some chlorite.

(3) Highly altered assemblage which has almost completely recrystallized to trioctillite with only remnants of randomly interstratified mixed-layer chlorite-saponite ramaining.

The alteration process can be summarized by noting that an assemblage of Mg-rich, Al-deficient clays (chlorite-talc-saponite) react with Al-rich clay (illite) and introduced potassium to generate the combined K-Mg-rich Al-poor phase trioctillite.

Discussion

Igneous rocks associated with salt rocks have not been commonly reported. Bodine (1971) has described basaltic flows associated with the Permo-Triassic evaporites, the Haselgebirge, in the Austrian calcareous Alps. In this case the basalts were altered completely into a K-feldspar-chlorite (clinochlore) assemplage with only magnetite remaining unaltered. Sokolov et al. (1975) have described the effects of dolerite sills in a halite-anhydrite succession in the Mikchanda area of the Siberian platform. They noted recrystallization and partial redeposition of halite, and, to a lesser extent, of the anhydrite and dolomite; the most pronounced effects occurred in the silicate (clay) assemblages where they observe the crystallization of talc, serpentine, tremolite, and epidote. We believe our quite different alteration suite, i.e. the formation of trioctillite, represents abundant mobile potassium in our salt assemblage as opposed to the Mikchanda K-deficient salt assemblage. Furthermore the

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Siberian sills are considerably thicker (4m and >15m) which would indicate a much longer time of cooling and the development of a much less pronounced thermal gradient away from the intrusions.

We suggest the chemical relations among the dike, the salt assemblages, and the associated host rock silicates are compatible and form a cohesive pattern.

Within the Yeso Hills occurrence the dikes intruded Ca-rich but Mg-K-Na-deficient salts. In this case wall rock reaction produced an altered igneous rock consistently lower in Mg and K but substantially enriched in Ca when compared to the Kerr-McGee altered dike compositions (Tables 2 and 6).

The Kerr-McGee altered dikes, however, were emplaced in rocks with high K, relatively high Mg and Na, and relatively low Ca content. Here we see an altered basalt highly enriched in K and Mg and depleted in Ca and Na. At the same time the host salts of the 10th ore zone become stripped of K as well as loose much of their Mg. We feel that the igneous intrusion exchanged Ca and Na for K and Mg with the salts to generate these unusually K-rich altered basalts.

This exchange is also reflected in the salztons and clay assemblages in the host salts. The generation of mobile K, Mg, and Na through salt-basalt exchange reactions exposed the clays to attack by the solutions. The trioctahedral clays were already saturated with magnesium; only the dioctahedral illite remained for further aggradation. We believe this was carried out through two possible generalized reactions:

$$\underset{\textit{illite}}{KAl_3Si_3O_{10}(OH)_2} + \underset{\textit{talc/saponite}}{3Mg_3Si_4O_{10}(OH)_2} + 2KCl \longrightarrow$$

$$\underset{\textit{trioctillite}}{3KMg_3AlSi_3O_{10}(OH)_2} + 6SiO_2 + 2HCl \qquad (1)$$

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$$KAl_3Si_3O_{10}(OH)_2 + 6SiO_2 + 2KCl + 9MgCl_2 \longrightarrow$$

illite *quartz*

$$3KMg_3Si_3O_{10}(OH)_2 + 10HCl + H_2O \qquad (2)$$

trioctillite

Reaction (1) requires the generation of free silica in the alteration assemblages while (2) requires the presence of free silica in the initial assemblage; both probably occurred and were controlled by the silica budget.

We suggest the altering solutions moved K and Mg down a concentration gradient toward the dike which maintained sufficiently high Mg/Ca for magnesite stability and K/Na for a K-rich trioctallite to crystallize. Ca and Na gradients decreased away from the dike such that plagioclase was partially destroyed in the dike and resulted in the crystallization of halite and anhydrite adjacent to the dike; much of the latter, because of high K and Mg concentrations, crystallized as polyhalite. We note and are not surprised that neither the transfer of Ca and Na had appreciable effects upon the host rock silicates since both Mg/Ca and K/Na in the solutions were too high from Na or Ca (alumino) silicates.

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UNFINISHED WORK AND RECOMMENDED ADDITIONAL WORK

1. Completion and refinement of the data presented in this report.

2. Additional samples and their study from (a) farther away from the Kerr-McGee dike occurrence within the 10th ore; (b) further investigation of the reported IMC occurrence and appropriate work if found; investigation of the polyhalite dikes with the same trend as the dike in the IMC workings; (c) extensive search for more silicate-rich sediments associated with the Yeso Hills occurrence and "grab" sampling at greater distances from the dike; then appropriate laboratory work. We are not happy with our results thus far from the Yeso Hills evaporite silicates.

3. We recommend that studies be carried out on the following: (a) K-Ar ages of the alteration micas in the dikes themselves, the trioctillite in salzton and host evaporites, the sylvite from unaltered 10th ore zone salts, the polyhalite adjacent to the dike and forming verticle veins in the IMC mine, and the unaltered illite in the unaltered host evaporite assemblages; this work must be accomplished elsewhere from samples prepared and submitted by us since we do not have appropriate isotope apparatus; (b) fluoride content in alteration micas from the igneous rock, the trioctillite, and the unaltered clays -- was fluorine a constituent of the magma and can we see it? (c) if funds permit, drilling angle holes with coring at appropriate intervals, to sample the dike and the effects of the dike upon adjacent barren halites, anhydrites, etc. below the 10th ore zone. The latter is particularly important toward learning of the effects of the dike in those intervals considered for disposal sites; we know nothing about the alteration associated with thick halite intervals.

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SUMMARY OF TENTATIVE CONCLUSIONS

1. The chemico-mineralogic features of the two dike exposures do not contradict the likelihood of their forming as part of a single igneous episode as part of single lineament of intrusive activity up to 75 miles long.

2. Metamorphic or alteration phenomena involve metasomatic exchange between the igneous rock and the evaporite host such that both are altered; alteration of both the dike and evaporite lithologies are substantially greater at the Kerr-McGee locality that in the Yeso Hills.

3. Chemico-mineralogic alteration of the host rock salts in the Kerr-McGee mine extends outward from the dike for ~12m; chemico-mineralogic alteration of salzton and silicate inclusions extends no more than ~5m from the dike. Replacement of sylvite by halite and anhydrite by polyhalite are the principal alteration features in the evaporite salts; replacement of talc-illite-trioctahedral clays (saponite-chlorite) by trioctillite, a new trioctahedral mica clay, is the major effect in the salzton and silicate inclusions in the salts. Alteration phenomena at Yeso Hills are much less intense and have remained obscure.

4. Textural effects of the intrusion are minimal. A thin zone of salt fusion occurred immediately adjacent to the dike which is preserved as an envelope of massive halite surrounding the dikes. Beyond this zone the texture, fabric, and bedding features of the host evaporites have remained unaffected. No fusion of the gypsum, then anhydrite, (because of $CaSo_4$'s considerably higher melting temperature) occurred at the Yeso Hills locality; original or near-original bedding features

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and fabric persist to the contacts with the dike.

ACKNOWLEDGEMENTS

We particularly want to thank Joseph Taggart, mineralogist with the New Mexico Bureau of Mines and Mineral Resources, for his valuable advice and enthusiastic assistance with some of our analytical problems. Pat Valentine, Geoscience secretary, for her clerical assistance; George Austin, also of the Bureau; and Robert Smith and Robert Jackson, two student technicians, are also gratefully acknowledged. We also wish to thank the management of the Kerr-McGee potash mine, in particular William Henderson the mine geologist, who cooperated most helpfully with this study.

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APPENDIX I

Selected x-ray diffractometer traces

I-2: Trioctillite with minor chlorite-saponite from <2μm EDTA insoluble residue of MB-76-3

A. Air-dried

B. Glycol-saturated

Note: trioctillite maxima (8.6, 17.4, 26.5°2θ) show no change with glycol saturation; small chlorite-smectite peak in air-dired trace at 7.1° becomes a doublet at 5.6 and 6.7°2θ in glycol-saturated trace.

I-3: Regularly stratified mixed-layer chlorite-saponite (corrensite) from <1μm fraction of EDTA-insoluble residue of MB-76-4

A. Air-dried

B. Glycol-saturated

Note: Only very slight shift of superlattice peaks with glycol-saturation (from 2.9 to 2.7°2θ). Major peak (002) shifts from 6.2 to 5.7°2θ.

I-4: Coarse fractions of EDTA-insoluble residues showing bulk mineralogy

A. MB-76-5 (>8μm fraction): Talc (9.3°2θ) and dioctahedral mica clay (8.8°2θ) major minerals. Minor quantities of chlorite (12.4°2θ) and plagioclase (27.8°2θ)

B. MB-76-4 (>8μm fraction): Talc is major mineral; lesser quantities of illite (8.8°2θ) and chlorite (12.4°2θ).

C. MB-76-3 (bulk residue -- almost no >8μm present): Trioctillite (8.6, 17.4, and 26.4°2θ) with minor randomly interstratified chlorite-saponite (7.2°2θ).

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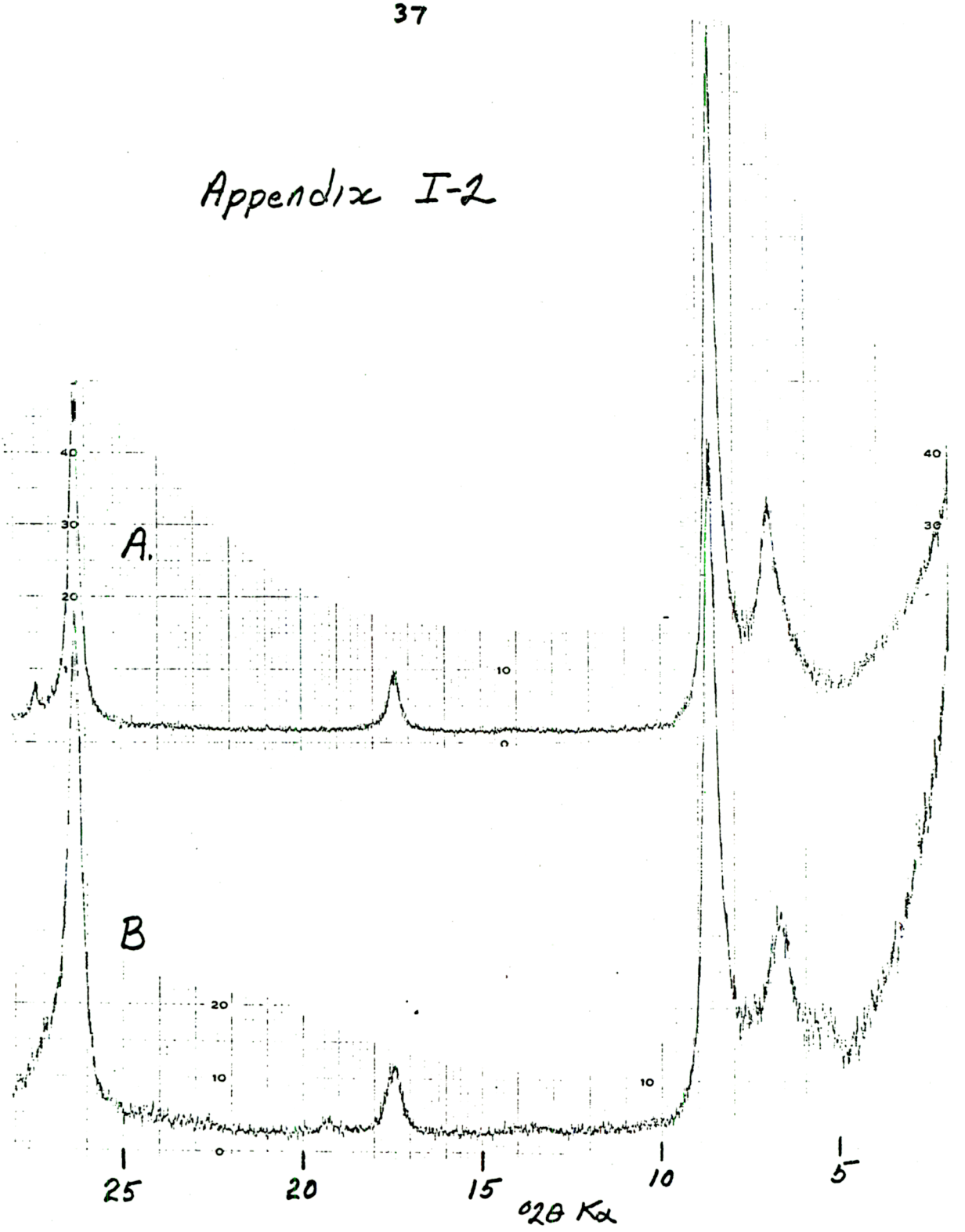
Appendix I-2



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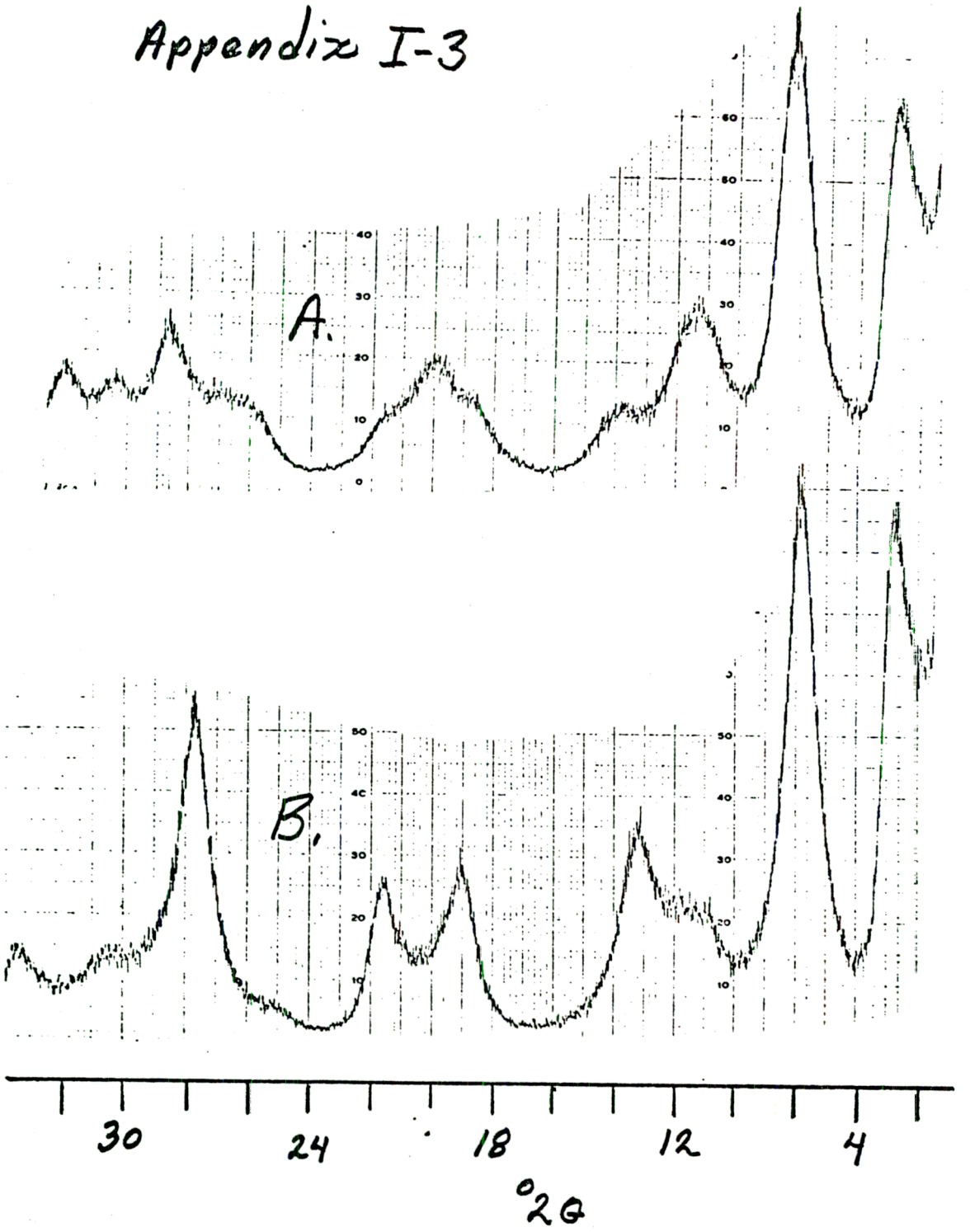
Appendix I-3



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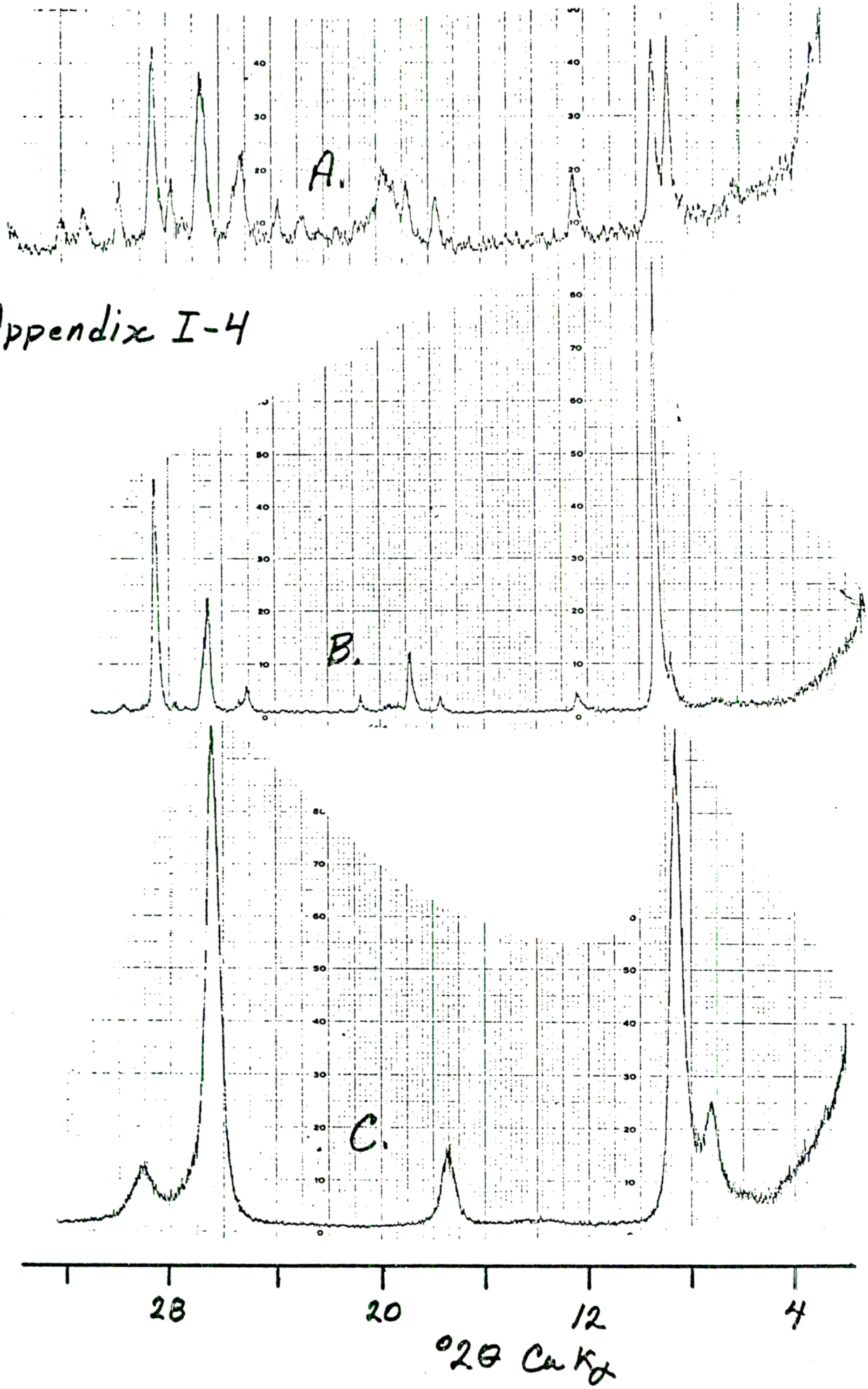
Appendix I-4



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