American Mineralogist, Volume 75, pages 1200–1204, 1990

Boggsite, a new high-silica zeolite from Goble, Columbia County, Oregon

DONALD G. HOWARD
Physics Department, Portland State University, P.O. Box 751, Portland, Oregon 97207-0751, U.S.A.
RUDY W. TSCHERNICH
Zeolite Research and Exploration, 526 Avenue A, Snohomish, Washington 98290-2414, U.S.A.
JOSEPH V. SMITH
Department of Geophysical Sciences, University of Chicago, 5734 South Ellis Avenue, Chicago, Illinois 60637, U.S.A.
GERALD L. KLEIN
3804 East Walnut Avenue, Orange, California 92669, U.S.A.

ABSTRACT

The new zeolite boggsite occurs as small, colorless-to-white, zoned hemispheres embedded in drusy tschernichite in small vesicles in dense Eocene basalt near Goble, Columbia County, Oregon, where it formed through the action of local hydrothermal activity. The mineral is orthorhombic, space group *Imma,* with $a = 20.21(2)$, $b = 23.77(1)$, and $c = 12.80(1)$ Å. The strongest X-ray diffraction lines are (in Å) 11.3(100), 4.43(70), 3.86(80), 3.37(100). The chemical composition is near $(Ca_{7.8}Na_{2.9}K_{0.2}Mg_{0.1})(Fe_{0.1}Al_{18.3}Si_{77.6})O_{192}\cdot 70H_2O$, with $Z = 1$, Si/Al = 4.24. It is optically biaxial (−), with $\alpha = 1.480(1)$, $\beta = 1.481(1)$, and $\gamma = 1.487(1)$, where $X = c$, $Y = a$, $Z = b$. The density is 1.98(1) g/cm³ (obs), 1.99 g/cm³ (calc). Tiny blades of boggsite with the forms {011}, {102}, {010}, {100}, and {001} elongated along the *b* axis have a morphology similar to that of thomsonite. The name honors Robert M. Boggs of Seattle, Washington, and Russell C. Boggs of Cheney, Washington.

INTRODUCTION

Two new zeolites have recently been discovered in close association in the Goble Basalts near Goble, Columbia County, Oregon. The more abundant of the two, tschernichite, is being described by Russell Boggs (personal communication). The name boggsite is given to the other zeolite, which was found by D.G.H. Its optical and physical properties and composition are described here.

Boggsite was named after Robert Maxwell Boggs of Seattle, Washington, and his son Russell Calvin Boggs of Cheney, Washington. Both have been prominent mineral collectors in the Pacific Northwest for many years and have worked hard in locating and characterizing the new mineral tschernichite.

The new mineral and the name boggsite were approved by the Commission on New Minerals and Mineral Names, I.M.A. Type specimens are on deposit with the American Museum of Natural History and the Royal Ontario Museum in Toronto.

OCCURRENCE AND GENESIS

Boggsite occurs on the top of a small projection of basalt located above a vertical cliff along Goble Creek, on the south side of the Neer Road, approximately 50 m west of the junction with Highway 30, 0.2 km north of Goble, Columbia County, Oregon. Wilkinson et al. (1946) mapped this area as the late Eocene Goble Volcanic Series, which consists of porphyritic basaltic flows, pyroclastics, and minor amounts of sediments. This area is overlain by 300 m of Oligocene sediments and Miocene Columbia River Basalt. Drilling shows the Goble Volcanics to be the basement rock in the area, extending to over 1520 m below the surface (Wilkinson et al., 1946).

The boggsite-bearing flow is composed of 0.6–2 m of basal flow breccia covered by a meter of highly vesicular basalt containing large, elongated, flattened gas cavities that decrease in size and number toward the fine-grained nearly nonvesicular center of the flow. The top of the flow has been eroded away. Boggsite was found only in a small area, 3 m by 2 m wide and 1 m thick, which represents a transition zone between the fine-grained, dense central portion of the flow and the highly vesicular basal portion of the same flow. The boggsite-bearing rock contains a few widely scattered vesicles, 1–5 mm and mostly spherical, but some flattened or tubular up to 1 cm long.

The primary minerals in the boggsite-bearing flow have a porphyritic texture with weak trachytic flow structure from alignment of the phenocrysts. The rock is composed of approximately 20% unaltered tabular labradorite-bytownite (An_{72}) crystals, 0.5–2.5 mm long; 5% clusters of unaltered green augite crystals, 0.2–4 mm long; 7% euhedral magnetite; 2% relic olivine, 1 mm in diameter (which is usually altered to chlorite and serpentine minerals); set in a groundmass (56%) composed of labradorite laths (An_{54}), augite, and magnetite along with less than

0003–004X/90/0910–1200$02.00

10% greenish brown to dark reddish brown devitrified intersertal glass. An orange-brown oxidized zone often extends 4–10 cm in from the joint surfaces.

Zeolites are abundant in the vesicular tops and bottoms of the basalt flows and flow breccia for over 2 km on each side of Goble Creek. The greatest number of species and largest quantity of zeolites are in the rock immediately adjacent to the vertical-walled canyon in which Goble Creek flows. The amount and number of species decrease away from the creek. Zeolite-filled veins, when present in the flow breccia, occur between fragments, but veins present in the dense part of the flows are vertical and nearly parallel to the canyon in which Goble Creek is found. General regional zeolization does not appear to be present; therefore the zeolites appear to have formed from hydrothermal solutions locally flowing up a vertical fault zone, which has subsequently been eroded by Goble Creek. When the solutions encountered porous sections of the Goble Volcanics, they flowed for a short distance horizontally, altering the basalt and depositing zeolites.

Zeolites line every cavity in the basal flow breccia and highly vesicular areas. A minor amount of smectite, covered by characteristically drusy heulandite, is followed by stilbite → analcime-cowlesite → garronite-phillipsite → levyne-thomsonite → mesolite → thomsonite → chabazite → calcite. Further from Goble Creek only drusy heulandite → stilbite → chabazite → calcite are found, or just drusy heulandite alone.

Intensity of rock alteration, amount of size of vesicles, and abundance of zeolites decrease toward the massive center of the flow. Black to dark green smectite becomes more abundant. Drusy heulandite becomes scarce, and zeolites are found only in a few cavities. In the more dense portions of the rock, large tschernichite crystals are found near the rims of the joint blocks of basalt. The tschernichite is often covered with okenite, analcime, levyne, offretite, erionite, opal, and chabazite, which are usually altered to white formless masses. Unaltered radial elongated prisms of heulandite, spheres of mordenite, and quartz are also present. Less commonly, cavities in the rim of the joint blocks contain colorless transparent analcime, levyne, and, rarely, blue thomsonite.

In a small localized portion of the dense rock, near the central portion of the flow where alteration is at a minimum, the rock is very fine-grained and nearly nonvesicular. Drusy tschernichite is present in every cavity, occasionally accompanied by a single boggsite hemisphere. The cavities at the very center of the flow contain only tiny smooth tschernichite hemispheres scattered on otherwise bare smectite or are devoid of any zeolite or smectite.

The sequence of crystallization at Goble has been determined from studies of thousands of specimens. Crystallization of boggsite and tschernichite represents an early hydrothermal phase that predated the more widespread zeolitization in the area, which commenced with the crystallization of drusy heulandite. In the boggsite-bearing rock, thin sheets of native copper or small mounds of calcite occasionally formed on the walls of some vesicles, followed by up to seven thin layers of dark green Fe-rich smectite, alternating with light green Fe-Ca-rich smectite, both darkening to black after exposure to air. Tschernichite was the first zeolite to crystallize, forming tiny, smooth, colorless hemispheres 0.1–0.5 mm, widely scattered on the smectite lining in nearly all the tiny vesicles. Boggsite usually formed as single, fine-grained, colorless, radial hemispheres, 0.5–1.5 mm in diameter, in only a few of the cavities. Very rarely, from two to seven boggsite hemispheres are present in one cavity, such as the one shown in Figure 1. Both tschernichite and boggsite continued to grow, with enlargement of the single hemisphere of boggsite, and tschernichite forming larger divergent crystals extending from the initial smooth hemispheres until the vesicle was completely lined. The two minerals have no tendency to form on each other.

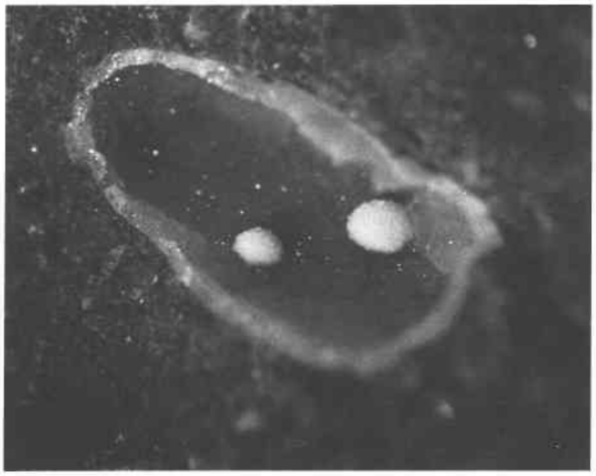

Fig. 1. Two hemispherical balls of boggsite in a cavity 10 mm long. The drusy lining is tschernichite. (Optical micrograph.)

Toward the end of crystallization both tschernichite and boggsite apparently became unstable and were partly dissolved. The surface of the boggsite turned white, whereas the interiors of the hemispheres were partly etched, often leaving voids or only a thin white hollow dome of boggsite. Rarely, small dark green Fe-rich smectite spheres crystallized on the interior roof and sides of the hollow domes and on the surfaces of both boggsite and tschernichite. At this point conditions favoring the crystallization of both boggsite and tschernichite were reestablished, and the resulting growth of both minerals caused the clay to be enclosed as inclusions. In a few cavities, the coarsest crystals of boggsite were produced during this final growth phase. The various growth phases are illustrated in Figure 2.

The crystallization of tschernichite and boggsite was followed rarely by the deposition of small cream-colored spheres of chalcedony, followed by heulandite, apophyllite, levyne, chabazite, calcite, aragonite, or opal. In the adjacent rock, which contains larger scattered tschernich-

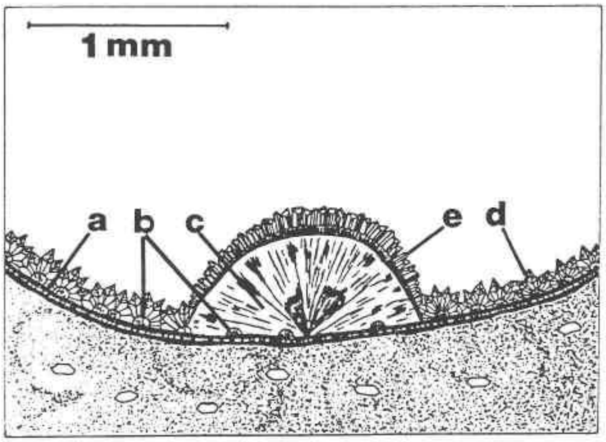

Fig. 2. Schematic drawing showing the various phases of growth: (a) banded smectite lining, (b) clear nuclei of tschernichite, (c) interior of boggsite ball, partially altered, with the *b* axis pointing radially outwards, (d) drusy tschernichite lining the cavity, (e) coarse crystal crust of boggsite.

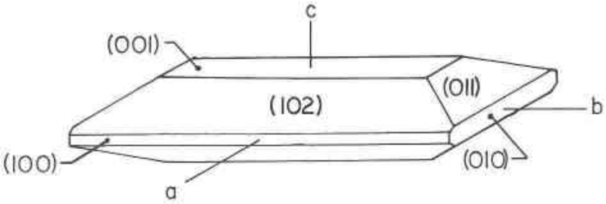

Fig. 3. Perspective drawing of the habit of boggsite crystals, showing the orientation of the axes and the principal faces.

ite without boggsite, a more complex crystallization occurred: native copper → smectite → okenite → tschernichite → okenite → opal → mordenite → okenite → levyne → offretite → erionite → heulandite → opal-analcime → okenite → chabazite, followed by alteration of all the low-silica species (okenite, levyne, offretite, chabazite, analcime) to chalky white masses.

A later, more widespread mineralization of the breccia and highly vesicular basalts involved the sequence of minerals associated with the crystallization of drusy heulandite. These solutions penetrated only the rims of some of the joint blocks, where the tschernichite, boggsite, and altered white masses of altered zeolites were covered.

Boggsite should be considered very rare. With the site apparently depleted, only 200 boggsite hemispheres have been found. Many were consumed to complete the characterization of the mineral.

PHYSICAL PROPERTIES

Boggsite is colorless to white, with a white streak. Zoned aggregates of boggsite range from 0.5–1.5 mm in diameter and usually appear white owing to altered internal layers or cavities within a hemisphere. The colorless, coarse crystals on the surface of the hemispheres are clear, transparent, and vitreous, with a brittle conchoidal fracture. White zones are translucent and dull. Boggsite does not exhibit any cleavage. The Mohs hardness is approximately 3.5.

Density measurements were made using the method of flotation in a liquid mixture (tetrabromoethane-ethanol). Variable results were obtained because the hemispheres invariably contain voids. To minimize this problem, the unaltered, colorless crystal crust of the hemispheres was used. This gave the highest density of all samples: 1.98 (1) g/cm^3. The calculated value, based on the chemical and structural data, is 1.994 g/cm^3, in good agreement with this experimental value.

Colorless, transparent boggsite does not fluoresce in ultraviolet radiation, but the white zones fluoresce a weak blue-white under both long and short wave ultraviolet radiation. Because of its high silica content ($Si/Al = 4.24$) boggsite is highly resistant to acids; it was unaffected after immersion in 6N HCl for one h.

OPTICAL PROPERTIES

Individual crystals of boggsite, ranging from 40–127 μm, were broken from the coarse crystal crust of a single boggsite hemisphere and studied using a spindle stage (Bloss, 1981).

Boggsite is biaxial (−) with $2V = 25°(6)$. The refractive indices are $\alpha = 1.480(1)$, $\beta = 1.481(1)$, $\gamma = 1.487(1)$ with orientation $X = c$, $Y = a$, $Z = b$. The low birefringence coupled with the small size yields a first-order gray color. The dispersion is relatively high with strong $r > v$. Extinction is parallel.

Crushed grain mounts of material from the central portion of a boggsite hemisphere have an average refractive index ranging from 1.46–1.47, which is lower than that of the crust. A thin section through a hemisphere showed further zoning. The central core displayed undulatory extinction for about a third of the sphere radius, followed by an amorphous layer with microbubbles, in turn followed by an outer layer of clear, terminated crystals.

MORPHOLOGICAL CRYSTALLOGRAPHY

Boggsite always occurs in intimate association with tschernichite (Fig. 1) as fine-grained, polycrystalline, zoned aggregates, 0.5–1 mm across, usually with a nearly smooth surface. A few aggregates, reaching 2 mm in diameter, are covered with coarse crystals (up to 0.5 mm long) that appear to be orthorhombic. They are elongated along the *b* axis and point radially outward. The crystals are chisel-shaped blades, with prominent forms {011}, {010}, {102}, and poorly developed forms {001} and {100}, as shown in Figure 3. The crystals are usually in contact on {001} but do not seem to form strongly oriented groups (see Fig. 4). The morphology of boggsite crystals closely resembles some habits of thomsonite. The presence of blades with small rectangular {010} termination serves to distinguish boggsite from the surrounding tschernichite,

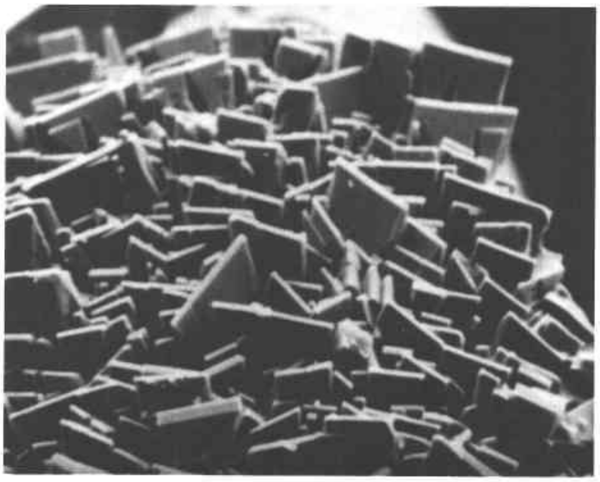

Fig. 4. The top layer of a ball of boggsite where second-growth crystals have formed. (Scanning electron micrograph. The field is 0.60 mm wide.)

whose termination is pyramidal, often with a rough (001) face.

X-RAY CRYSTALLOGRAPHY

Small boggsite hemispheres were mounted on glass needles in a Debye-Scherrer powder camera and studied with Cu*K*α radiation. The *d* values obtained are summarized in Table 1. Approximate intensities were assigned visually. Least-squares fitting of the *d* values gave cell dimensions a = 20.21(2), b = 23.77(2), and c = 12.80(1) Å. Independent determinations by Pluth et al. (1989) and Pluth and Smith (1990) during single-crystal studies are in good agreement, giving a = 20.236(2), b = 23.798(1), and c = 12.789(1) Å and the space group *Imma*.

The first set of cell dimensions was used to calculate the theoretical *d* values given for comparison in Table 1. Theoretical intensities were calculated using the framework structure determined by Pluth and Smith (1990), Pluth et al. (1989), and the computer program POWD 12 (Smith, 1988).

Table 1. X-ray diffraction data for boggsite

			Calculated		Observed	
h	*k*	*l*	*d**	Intensity**	*d*	Intensity
0	2	0	11.884 Å	33	11.8 Å	30
0	1	1	11.269	100	11.3	100
2	0	0	10.106	24	10.2	30
2	2	0	7.699	3	7.69	10
0	3	1	6.736	15	6.75	20
3	0	1	5.962	10	5.96	10
0	2	2	5.634	7	5.57	5
2	3	1	5.605	1		
4	0	0	5.053	5	5.03	10
0	5	1	4.456	34	4.43	70
0	4	2	4.354	31		
5	0	1	3.855	86	3.86	80
5	2	1	3.667	13	3.63	30
3	0	3	3.604	31		
5	1	2	3.383	31	3.37	100
6	0	0	3.369	2		
0	6	2	3.368	63		
2	6	2	3.195	9	3.18	10
0	5	3	3.175	4		
1	3	4	2.935	3	2.928	10
5	0	3	2.934	6		
1	6	3	2.873	6	2.861	10
3	1	4	2.869	3		
5	5	2	2.775	5	2.753	10
5	6	1	2.763	1		
5	4	3	2.631	15	2.627	20
0	9	1	2.586	11	2.557	20
7	4	1	2.545	2		
8	0	0	2.527	2		
7	3	2	2.498	2		
5	3	4	2.392	2	2.372	10
2	3	5	2.368	2		
5	6	3	2.358	4		
5	8	1	2.353	1		
7	6	1	2.296	2	2.304	3
3	8	3	2.293	1		
0	9	3	2.245	3	2.249	3
9	0	1	2.212	1	2.215	5
10	0	0	2.021	7	2.023	5
8	0	4	1.983	7	1.980	10
0	12	0	1.981	2		
8	5	3	1.977	2		
3	9	4	1.950	7	1.951	5
0	6	6	1.878	1	1.875	3
3	5	6	1.870	2		
5	9	4	1.819	4	1.819	5
10	6	2	1.733	1	1.733	3
3	11	4	1.731	1		
0	12	4	1.684	1	1.688	3
8	5	5	1.682	1		
0	14	2	1.641	4	1.641	20
0	15	1	1.572	2	1.572	15
8	4	6	1.572	1		

* Calculated using the cell dimensions $a = 20.21$, $b = 23.77$, $c = 12.80$ Å.

** Calculated using POWD12 (Smith, 1988), including only the 96 tetrahedral sites (assumed to be occupied by Si) and 192 O sites, as determined by Pluth and Smith (1990).

CHEMICAL COMPOSITION

A sample of approximately 10 mg of boggsite was prepared from about 40 specimens that had been stored indoors for several months. The boggsite was separated as thoroughly as possible from the surrounding tschernichite and subjected to CHN (carbon-hydrogen-nitrogen) analysis, giving 17.0(2)% H_2O. Owing to the limited amount of boggsite available, electron probe energy-dispersive analysis was the only practical means of obtaining further chemical data. Since the measurements were carried out in a vacuum, H_2O loss may have occurred.

A vesicle 1.6 mm in diameter was sliced slightly off center through a hemisphere of boggsite. Analyses were made using a Cameca SX-50 probe operating in the energy-dispersive mode at 15 kV and 2 nA. The standards used were An_{70} glass, microcline (Asbestos, Quebec), and manganoan fayalite. Repeated analysis on the same spot showed a major change in Na over several min of beam exposure for a spot size less than 40 μm. A beam diameter of 50 μm was therefore employed in the measurements.

A total of 42 analyses was made at various points across the hemisphere and averaged. Those analyses with significantly lower totals from the mean were discarded, assuming that they had been adversely affected by the small

Table 2. Chemical composition of boggsite

Oxide	Wt%	Number per unit cell**	
SiO_2	63.01 ± 0.72	Si	77.61
Al_2O_3	12.60 ± 0.22	Al	18.29
Fe_2O_3	0.11 ± 0.13	Fe(+3)	0.10
MgO	0.07 ± 0.06	Mg	0.13
CaO	5.89 ± 0.14	Ca	7.77
Na_2O	1.23 ± 0.25	Na	2.94
K_2O	0.10 ± 0.05	K	0.16
		O	192.24
H_2O	17.0 ± 0.2	H_2O	69.9
Total	100.01		

* Electron microprobe analysis: mean and range (1 σ). See text for statement on possible systematic errors and normalization. I.M. Steele, analyst.

** Numbers per unit cell, based on 96 tetrahedral sites. For a perfect framework, the number of O atoms should be 192. The tetrahedral sites are assumed to be occupied by Si + Al + Fe.

voids present throughout the sample. The remaining oxide totals exclusive of H_2O averaged 86.7%. Since the residual (13.3%) is considerably less than that obtained in the separate determination of bulk H_2O, it was presumed that some H_2O was lost during sample preparation. This is typical of zeolites with wide channels (e.g., faujasite and mordenite). The averaged weight percentages of oxides were normalized to a total of 83.0% to adjust for lost H_2O.

The analytical results are summarized in Table 2. Calculations based on 96 tetrahedral sites, as found in the structure analysis (Pluth and Smith, 1990; Pluth et al., 1989), with the assumption that only Fe enters the tetrahedral sites with Al and Si, yielded the rounded-off formula $(Ca_{7.8}Na_{2.9}K_{0.2}Mg_{0.1})(Fe_{0.1}Al_{18.3}Si_{77.6})O_{192}\cdot 70H_2O$.

Some chemical variation occurs in the boggsite specimens, but the paucity of the material precludes detailed evaluation. Also, since the multiplicities of the structural positions are 16 and 8, site substitution and disorder must occur (Pluth and Smith, 1990).

Using the measured density of 1.98 g/cm³ together with the optical and chemical data presented, the Gladstone-Dale relationship (Mandarino, 1981) gives a compatibility index of −0.057, which is considered good.

ACKNOWLEDGMENTS

The authors give special thanks to R.P. "Yogi" Manuel for allowing major excavation on his property. We thank Robert Petty of the Marine Sciences Analytical Laboratory of the University of California, Santa Barbara for the CHN analysis of H_2O content, and I.M. Steele of the University of Chicago for the energy-dispersive X-ray study. We also thank J.A. Mandarino of the Commission on New Minerals and Mineral Names, I.M.A., for his patience and constructive questions, which improved the consistency of our results.

This is Portland State University Environmental Sciences and Resources publication no. 244. J.V.S. is supported by NSF grant CHE-8618041.

REFERENCES CITED

Bloss, F.D. (1981) The spindle stage: Principles and practice. Cambridge University Press, New York.

Mandarino, J.A. (1981) The Gladstone Dale relationship—Part IV: The compatibility concept and its application. Canadian Mineralogist, 19, 441–450.

Pluth, J.J., and Smith, J.V. (1990). Crystal structure of boggsite, a new high-silica zeolite with the first three-dimensional channel system bounded by both 12- and 10- rings. American Mineralogist, 75, 501–507.

Pluth, J.J., Smith, J.V., Howard, D.G., and Tschernich, R.W. (1989) Boggsite; the first three-dimensional channel system with both 12- and 10-rings. In J.C. Jansen, L. Moscou, and M.F.M. Post, Eds., Zeolites for the Nineties, Recent Research Reports, 8th International Zeolite Conference, p. 111–112. Amsterdam.

Smith, D.K. (1988) X-ray diffraction powder generation package POWD12. Materials Research Laboratory, Pennsylvania State University, University Park, Pennsylvania.

Wilkinson, W.D., Lowry, W.D., and Baldwin, E.M. (1946) Geology of the St. Helens quadrangle, Oregon. Oregon State Department of Geology and Mineral Industries, Bulletin 31, p. 39.

MANUSCRIPT RECEIVED OCTOBER 26, 1989
MANUSCRIPT ACCEPTED JULY 3, 1990