MINERALOGICAL MAGAZINE, DECEMBER 1979, VOL. 43, PP. 479-82

A note on low-grade contact metamorphism—southwestern Brewster County, Texas

MARVIN J. DRODDY

Bendix Field Engineering Corporation, Geology Division, Austin, Texas

AND

JOHN C. BUTLER

Department of Geology, University of Houston, Houston, Texas 77004

SUMMARY. Intrusion of the Bee Mountain soda microsyenite plug in southwestern Brewster County, Texas established conditions of low grade contact metamorphism in the upper Cretaceous Boquillas and Pen Formation sedimentary rocks. It is unlikely that load pressure exceeded 330 bars or that temperatures exceeded 470 °C at the intrusive contact. Thermally unaltered parent materials predominantly contain ortho- and allochemical low-magnesium calcite, silt-sized quartz, calcium montmorillonite, kaolinite, and volcanic glass. Incipient metamorphism is marked by the appearance of xanthophyllite followed by prehnite formed at the expense of xanthophyllite and montmorillonite. Near the soda microsyenite contact prehnite has decomposed to yield grossular and epidote group minerals, and apophyllite has replaced calcite where fluorine-bearing solutions have reacted with the parent material. Textural modifications include the recrystallization of calcite, redistribution of some of the mineral phases, and decreased friability in the marly layers.

MUCH field and experimental effort in recent years has been confined to what has been described as zeolite facies or depth-of-burial metamorphism of medium to high pressure (summarized in Turner, 1968), but there is a relative paucity of information dealing with incipient contact metamorphism at relatively low pressure.

In southwestern Brewster County, Texas (fig. 1), numerous shallow intrusives ranging in composition from fayalite-bearing granite to gabbro intrude Cretaceous and post-Cretaceous sedimentary rocks (Lonsdale, 1940 and Maxwell *et al.*, 1967). In this region, low-grade contact metamorphic effects have been thought to be confined to: (1) bleaching and induration; (2) silification of carbonates near intrusive-carbonate contacts; (3) presence of analcime in sedimentary rocks cut by intrusive rocks which contain analcime; and (4) solution and redeposition of calcite resulting in the genesis of spotted rocks (Yates and Thompson, 1959).

Low-grade contact metamorphic parageneses are well developed along the northeastern and eastern margins of Bee Mountain (fig. 1), which is located along Texas state highway 118, 3 km north of Study Butte, and 6 km north of the western entrance to Big Bend National Park (Butler, 1972 and Droddy, 1974). The purpose of this note is to describe the effects of incipient contact metamorphism which have modified the mineralogy and texture of the sedimentary rocks cut by the Bee Mountain intrusion.

Bee Mountain is a 0.75 km diameter plug-like mass with a potassium-argon age of 34.9 (± 1) Ma. (Mike Daily, personal communication, 1978). The predominant rock type exposed within the mass is soda microsyenite porphyry. Detailed X-ray powder diffraction analyses of separated alkali feldspar phenocrysts and groundmass concentrates by Patel (1973) using techniques developed by Wright and Stewart (1968) suggest that the maximum intrusion temperature was between 750 and 800 °C. We believe that the preservation of low sanidine structural states and the absence of hydroxyl-bearing phases are indicative of rapid cooling under nearly water-free conditions.

On the eastern and northeastern margins of Bee Mountain the soda microsyenite has intruded the late Cretaceous Boquillas and Pen Formations, which consist of medium bedded (up to 0.5 m) argillaceous limestone flags that alternate with thin (usually less than 2 cm) layers of marl, and units of tuff and bentonitic clay (Maxwell *et al.*, 1967). The load pressure at the time of intrusion is estimated to have been 0.4 kb. This is based on a section density of 2.6 g/cc and a measured section of approximately 1200 m (Maxwell *et al.*, 1967).

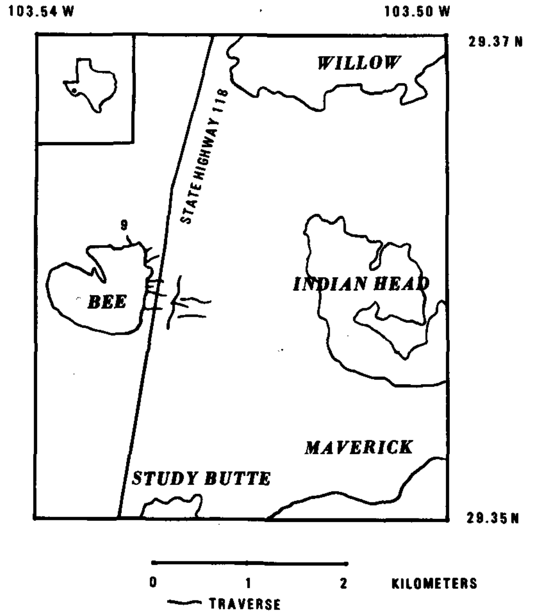

FIG. 1. Location of the study area with the location of traverse 9 indicated.

Mineralogy of the unaltered limestone and marl. There are three major intrusive masses within 4 km of the eastern flank of Bee Mountain (Maverick, Indian Head, and Willow mountains, fig. 1). Preliminary potassium-argon dating supports the idea that all of these bodies were cooling at about the same time and it is unlikely that thermally unaltered samples of limestone and marl are to be found in the immediate vicinity of Bee Mountain itself. Samples of unaltered limestone and marl (five samples each) were collected near Villa de la Mina which is approximately 8 km west of Bee Mountain and some 5 km from the nearest surface-exposed large intrusion. X-ray powder diffraction analysis of the bulk material and of the acid insoluble (5% HCl) residue allows description of the unaltered Boquillas and Pen marls and limestones. The limestones contain an average of 21% (by weight) of non-calcareous material; quartz, kaolinite, illite (lMd), and a small quantity of volcanic glass constitute the acid-insoluble fraction. Marls contain an average of 45% non-calcareous material. Quartz, calcium montmorillonite (d_{001} expands from 15.5 Å to 17.4 Å in ethylene glycol vapour at 80 °C), volcanic glass and a trace amount of kaolinite. Redfield (1940) also observed the presence of glass in the insoluble fraction of Boquillas limestones in the Brewster County area. Calcites in the unaltered samples have low magnesium contents (less than 2 mol per cent as estimated from the *d*-spacings of the primary diffraction maxima) and no other carbonate phases have been detected.

Silicate parageneses. A total of seventy-nine samples (from eleven traverses) were collected along traverses extending from the northeastern and eastern flanks of Bee Mountain. Thin section examination and X-ray powder diffraction analysis of bulk samples and mineral separates have enabled a detailed investigation of mineralogical and textural variations as a function of position with respect to the soda microsyenite contact.

In the parent material, calcium montmorillonite, kaolinite, and volcanic glass appear to be the most reactive phases; light brown masses of analcime also occur in about 25 per cent of the samples examined, but its distribution does not appear to reflect distance from the intrusive contact. It tends to be concentrated in oval buttons a few millimetres in length which stand above the calcite matrix on weathered surfaces. Unit cell parameters (*a*) range from 13.66 to 13.73 Å (±0.01 Å), and completely cover the tri-fold genetic classification of natural analcimes proposed by Coombs and Whetten (1967). No analcime has been found in samples of unaltered limestone, and as the distribution of analcime in the mapped area appears to be unrelated to the intrusive contact, we believe that the analcime formed by a reaction between warm interstitial water, glass, and calcium montmorillonite present in the parent material. Variations in the unit cell dimensions of the analcimes most likely reflect variations in the composition of the parent material.

The initial metamorphic phase to form in the study area is xanthophyllite, which is restricted to areas relatively far removed from the soda microsyenite contact. In hand specimen, xanthophyllite occurs as amber, subhedral to euhedral plates that are as large as 0.5 mm. In thin section, the plates are pleochroic yellow to reddish brown, biaxial negative, and have a 2V of less than 5°. X-ray powder diffraction of hand-picked grains provided the strongest parameter for identification. The most likely source of component elements for this mica appears to be montmorillonite and other clay minerals, but petrographic examination did not reveal any relationship between these phases.

Some xanthophyllite-bearing samples also contain metamorphic albite, which occurs in a microcrystalline matrix with analcime and quartz, or as subhedral to euhedral grains as large as 0.25 mm. These feldspars comprise as much as 60 per cent of some samples. Terrigeneous plagioclase grains also occur in these rocks; they are distinguishable from metamorphic forms by their distinctive grain boundaries, lack of carbonate inclusions, and rounded margins.

At fluid pressures less than 1 kilobar, analcime will react with quartz to form albite and water at 200 °C (Liou, 1971*b*). Distribution of metamorphic albite reflects the distribution of quartz and analcime in the present material as well as the attainment of temperatures approaching 200 °C. In the absence of quartz, analcime decomposes to albite, nepheline, and fluid at 470 °C and 0.33 kb P_{H_2O} (Liou, 1971*b*). As analcime was found in samples collected at the intrusive contact, we doubt that temperatures in the country rock exceeded 470 °C.

In samples collected nearer the intrusion, the layer silicate prehnite occurs as a replacement of xanthophyllite, montmorillonite, and calcite. It forms colourless sheaf-like clusters of bladed crystals as large as 0.08 mm; microscopic intergrowths with xanthophyllite were observed in some samples.

Coombs *et al.* (1970) suggested that prehnite could form from a mixture of kaolinite and calcite at slightly less than 300 °C and 0.3 kb P_{H_2O} if the chemical potentials of CO_2 and H_2O were nearly equal. Robinson (1973) reported the presence of prehnite in a contact metamorphic aureole of the Whin Sill in northern England, so we believe that we are reporting only the second occurrence of prehnite as part of a contact metamorphic assemblage.

The highest-grade metamorphic assemblage in the Bee Mountain area is represented by grossular and epidote group minerals (zoisite and epidote). The garnet crystals are as small as 0.005 mm in diameter, and are frequently clustered into oval-shaped and elongated aggregates 0.02 to 0.06 mm in diameter. Within a few metres of the intrusive contact, individual garnets are as large as 0.04 mm in diameter, and often bounded by distinguishable crystal faces. The colour of the garnets ranges from milky white to medium grey; in general, the darker the garnet, the greater the percentage of small inclusions. As much as 70 per cent by weight of some of the samples is contributed by the garnet fraction. The unit cell dimension (*a*) from 10 garnet samples ranges from 11.87 Å to 11.91 Å (±0.01 Å), which is close to that of pure grossular.

Zoisite and epidote occur with grossular in eight of the samples, and comprise trace amounts up to as much as 19 per cent of some samples. Zoisite forms colourless clusters of bladed crystals which average 0.045 mm in length, and as colourless anhedral grains 0.03–0.15 mm in diameter. Elongate grains display straight extinction and are distinguished from the accompanying epidote by optic sign.

The decomposition of prehnite to zoisite + grossular + quartz + fluid has been the subject of experimental studies by Strens (1968) and Liou (1971*a*). At 0.3 kb P_{H_2O}, this reaction takes place at approximately 400 °C. Grossular and epidote minerals tend not to occur with prehnite in the study area and are restricted to areas close to the soda microsyenite contact, where maximum temperatures were realized, and this reaction (or one similar to it) was probably operative.

Winkler (1976) considers the disappearance of prehnite and the formation of epidote group minerals to mark the beginning of 'low-grade' metamorphic conditions, and the assemblage albite + epidote + zoisite represents the albite-epidote hornfels facies of Turner (1968).

The metamorphism of these rocks apparently was not isochemical; besides the loss of volatile components such as H_2O and CO_2, metasomatic replacement of calcite by apophyllite occurred in fourteen of the samples. This mineral comprises 1–41 per cent (by weight) of the samples. All of the samples containing apophyllite were collected within a few metres of the intrusive contact. Apophyllite occurs both as a fracture filling and as a replacement of calcite; the micritic matrix appears to have been more susceptible to replacement than the biogenic allochems although a complete replacement of all calcite forms has been observed. We believe that this is the first reported occurrence of apophyllite in West Texas.

Of the eleven traverses studied in detail (fig. 1) only number 9 displays a complete, uninterrupted paragenetic sequence. The remaining traverses either exhibit only a part of the sequence or are complicated by a small northwest-southeast trending anticline that has Bee Mountain microsyenite exposed at its core. Traverse 9 was taken from the northern margin of the mass where the microsyenite contact is nearly vertical. The silicate paragenetic sequence is illustrated in fig. 2.

Textural modifications. Alteration of colour, sedimentary structures and textures are associated with the metamorphism of the Boquillas marls and limestones. Samples of thermally unaltered limestones

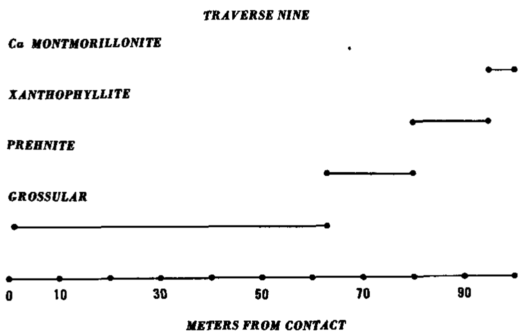

FIG. 2. Distribution of silicate phases along traverse 9.

are various shades of brown and grey (USGS colours 10YR4/2–10YR6/2); near the contact with the microsyenite most of the rocks lack the brown colouration and are various hues of grey (USGS colours N3–N7). This is in general agreement with the observation of Yates and Thompson (1959) that intrusion produced a bleaching of the country rocks; however, rocks which contain abundant grossular are frequently black in colour.

Some beds near the contact approach two metres in thickness, which is four times the maximum thickness measured in thermally unaltered areas in Brewster County (Droddy, 1974 and Maxwell *et al.*, 1967). This apparent increase in thickness is a result of mineralogical and textural modifications in the marl units which caused the marls to merge with the biomicrites.

Both allochemical and orthochemical calcite have been recrystallized; the maximum diameter of the recrystallized orthochemical calcite is 20 microns in the slightly modified rocks and up to 1 mm in rocks adjacent to the contact with the microsyenite. Foraminifera tests are still recognizable within a few millimetres of the contact.

Concluding remarks. The silicate parageneses described in this note are not restricted to the Bee Mountain contact aureole. Preliminary sample collection and processing has revealed similar contact assemblages wherever shallow intrusives have intruded the Boquillas Formation in southwestern Brewster County, Texas. As there is a considerable variation in intrusive composition (Maxwell *et al.*, 1967), we believe that there is a corresponding intrusion temperature variation and detailed mineralogical analyses of samples from other contact aureoles will result in the extension of our knowledge of incipient low grade contact metamorphism.

REFERENCES

Butler (J. C.), 1972. *Annual Meeting of the Texas Academy of Sciences*, San Marcos, Texas, 26 (abstr.).

Coombs (D. S.), Horodyski (R. J.), and Naylor (R. S.), 1970. *Am. J. Sci.* **268**, 142–56.

—— and Whetten (J. T.), 1967. *Geol. Soc. Am. Bull.* **78**, 269–82.

Droddy (M. J.), 1974. Unpublished MS thesis, University of Houston, Houston, Texas.

Liou (J. G.), 1971*a*. *Am. Mineral.* **56**, 507–31.

—— 1971*b*. Lithos, **4**, 389–402.

Lonsdale (J. T.), 1940. *Geol. Soc. Am. Bull.* **51**, 1539–1626.

Maxwell (R. A.), Lonsdale (J. T.), Hazzard (R. T.), and Wilson (J. A.), 1967. *Texas Bureau of Economic Geology* pb. 6711, 320 pp.

Patel (A. K.), 1973. Unpublished MS thesis, University of Houston, Houston, Texas.

Redfield (R.), 1940. Unpublished MS thesis, University of Texas, Austin, Texas.

Robinson (D.), 1973. *Am. Mineral.* **58**, 132–3.

Strens (R. G. J.), 1968. *Mineral. Mag.* **36**, 846–67.

Turner (F. J.), 1968. *Metamorphic Petrology*: McGraw Hill, 403 pp.

Winkler (H. G. F.), 1976. *Petrogenesis of Metamorphic Rocks*: Springer-Verlag, 334 pp.

Wright (T. L.) and Stewart (D. B.), 1968. *Am. Mineral.* **53**, 33–88.

Yates (R. G.) and Thompson (G. A.), 1959. *U.S. Geol. Surv. Prof. Pap.* **321.**

[*Manuscript accepted for publication 20 July 1979*]