Permian Evaporite Deposits of the Italian Alps (Dolomites): The Development of Unusual and Significant Fabrics

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ABSTRACT

Evaporitic and evaporite related deposits in the Dolomite Mountains of Italy show a variety of deformational features superposed upon depositional fabrics. Features typical of sabkha deposits (supratidal) and shallow-water subaqueous gypsum deposits are found locally. In many areas original features have been diagenetically altered or destroyed by later tectonism. This tectonic deformation has resulted in deformational fabrics that are gneissic, augen-like and mylonitic in appearance. These textures are found in gently dipping, unfolded strata as well as in tightly folded beds. Recognition of these deformational fabrics underscores one of the difficulties involved in interpretation of ancient evaporite sequences. It, however, also adds to the compendium of known and recognizable evaporitic structures and points up their significance.

INTRODUCTION

The occurrence of evaporites in the geologic record is far from common. The limited occurrence of these rocks reflects neither their original volume nor their geologic and economic importance. Their present abundance merely reflects their "preservability" as part of the geologic column. Relatively few geologists have the opportunity to study evaporites on outcrop or from borehole material (Hanford et al., 1982). Yet, as with their limited occurrence, this does not detract from their importance. Rather, the amount of increased and diversified study these rocks have received in the last 15 to 20 years is an indication of the growing importance with which they are viewed.

The depositional environments of evaporites have been well studied and the characteristics of the various environments and facies well documented (Schreiber and Decima, 1975; Schreiber, 1978; Kendall, 1979a,b; Butler et al., 1982; Dean and Anderson, 1982; Loucks and Longman, 1982; and others). More recently, the diagenesis of evaporites has become of interest. Loucks and Longman (1982, p. 131) cite a variety of studies that show how depositional textures may be altered diagenetically and can lead to incorrect interpretations.

Similarly, textures and fabrics induced in evaporites by tectonism can be, and have been, misinterpreted or not appreciated by some earlier workers. Previous work on deformation structures in evaporites has tended to be concentrated on halite and the high salts of potassium and magnesium, since these are more prone to deform because of their greater ductility. Less study has been focused on anhydrite and gypsum deformation.

Previous work on deformational fabrics found in anhydrite suggests that distorted anhydrite results primarily from one or several diagenetic processes (Maiklem et al., 1969). We feel that additional distortion features require tectonic deformation. Other work suggests that gypsum and anhydrite deformation was induced by salt deformation (see, for example, Wall et al., 1961; Evans, 1967; Martinez, 1974). However, deformed gypsum and anhydrite occur where there is no halite or "high" salts, nor evidence of their former presence.

This paper describes deformed sulfate rocks in the Bellerephon Formation (Upper Permian) of the Dolomite Mountains of northern Italy, Southern Alps (Figure 1). These rocks exhibit a wide variety of deformational features, some of which mimic sedimentary features and sedimentary facies which are not in fact present.

STRATIGRAPHY

The upper Permian Bellerephon Formation of the Dolomite Mountains is composed of supratidal (sabkha) and restricted, shallow-subaqueous evaporitic rocks and asso-

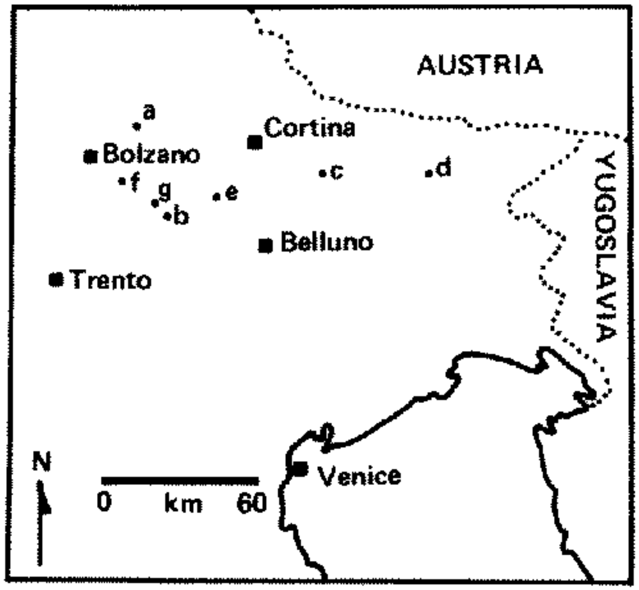

Figure 1. Location Map. Localities mentioned in text are: a) Passo Brogles near the city of Ortiese; b) San Martino di Castrozza; c) Lozzo di Cadore; d) Comeglians; e) Rifugio Flora Alpina near the town of Falcade; f) Passo Valles; g) Vigo di Fassa.

ciated carbonates. These rocks are underlain by a sequence of continental sandstones and siltstones, which are mostly fluvial and flood plain deposits. The overlying Triassic age rocks are dominantly more open marine carbonates. The calcium sulfate rocks of the Bellerephon Formation range from less than 50 to 100 meters thick near the basin margin to more than 500 meters thick at the basin center (Bosellini and Hardie, 1973). The sulfates are now secondary gypsum after anhydrite on outcrop.

DEFORMATION

Exposures of the Bellerephon Formation show a broad range of deformational fabrics and features ranging from slightly deformed to strongly tectonized. Many of the deformational fabrics were not previously identified because of their superficial resemblance to sedimentary features or because they do not appear to be deformed (Schreiber et al., 1982).

The section seen at Passo Brogles near the city of Ortiese appears at a distance to be an undeformed homoclinal sequence dipping 25° to the southeast. However, closer examination of the sulfate-bearing beds of this section reveals the presence of numerous small-scale, bedding parallel, isoclinal folds within bedding planes (Figure 2). These folds have wavelengths on the order of 3 to 4 centimeters

Figure 2. Isoclinal folding within bedding planes. Note preferential thickening of most fold noses. Dolomite layer directly below pen exhibits no visible folding. This seems to be a result of bed thickness and the greater competency of the material.

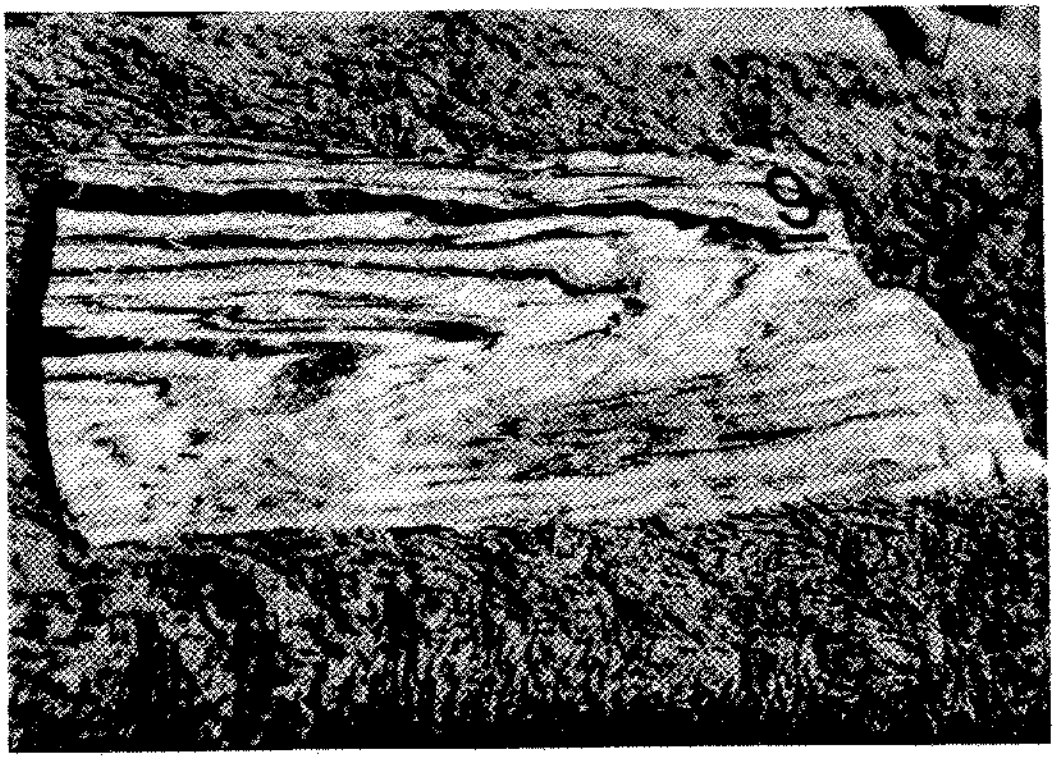

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Figure 3. a) Small scale isoclinal folds. Note the preferential thickening of noses, but bedding thickness appears to be approximately equal. Size of sample is 15 cm × 8 cm. NUMBER ON SAMPLE DOES NOT REFER TO FIGURE NUMBER. b) Thinner beds of dolomite behave in a somewhat ductile fashion. Size of sample is 10 cm × 6 cm.

and amplitudes on the order of 7 to 8 centimeters, but the size of the folds, as well as their style, varies considerably. The folds may best be described as similar folds with thickened hinges and thinned limbs. Because the sequence of rocks does not appear to be folded, these structures may be described as intrafolial folds (Hobbs et al., 1976).

These folds are defined by alternating layers of alabastrine gypsum and dolomite. This layering is most probably original bedding, because in those beds which are undeformed primary sedimentary structures are still evident. The folds are best developed when the thickness of the dolomite and gypsum layers are approximately equal and on the order of 3 to 4 millimeters thick, or when the layers of gypsum are slightly thicker (Figure 3). These rocks have a gneissic appearance resulting from the combination of isoclinal folding and compositional layering.

The fabrics seen in the Passo Brogles section are also found in other locations (for example, at Passo di Valles and near the town of Vigo di Fassa). In addition, other features are also found. Locally, the appearance of these folds changes, with the noses of some folds becoming even more thickened as the limbs thin. This is particularly true of the dolomite interlayers, as they seem to be more important in defining the nature of the folds (Figure 4). This variation in style can occasionally be seen in the same bedding horizon (Figure 2). The noses of the folds and/or the limbs may become attenuated to the point that layering becomes indistinct. Finely comminuted fragments of dolomite seem to become enmeshed in a gypsiferous matrix (Figure 5). Rocks of this type may best be described as mylonitic, or having a mylonitic texture.

Another fabric that is associated with the attenuation of dolomite is that of pseudo-crossbedding. This feature, which mimics an original sedimentary structure, is clearly illustrated in Figure 6. Careful inspection of the sample reveals that the portion of the rock that appears to be crossbedded is not. What is present are very thin (1 millimeter or less) layers of dolomite that are isoclinally folded. Facies analysis of the Bellerephon Formation has not revealed an evaporite facies with crossbedding as a primary sedimentary structure. Also visible are fragments of dolomite that have been fractured, rotated and drawn out within the gypsum matrix (Figure 6). This mode of deformation is often found in those locations in which either the dolomite layers or the sulfate layers (generally the latter) are preferentially thickened during deposition or tectonism, or where strain appears to have been locally more intense. Samples from a quarry near the town of San Martino di

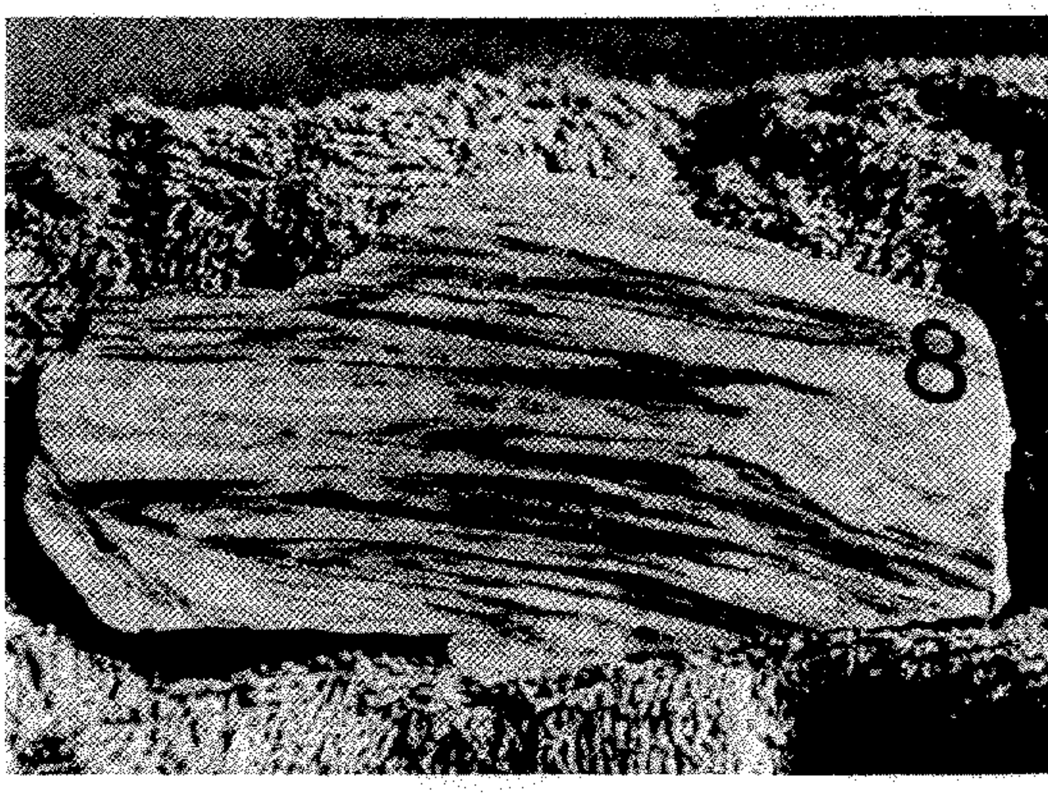

Figure 4. Sample shows preferential thickening of noses of folds and attenuation of limbs, particularly in the dolomite layers. As this occurs the rocks become more and more mylonitic in appearance. Size of sample is 11 cm × 6 cm. NUMBER ON SAMPLE DOES NOT REFER TO FIGURE NUMBER.

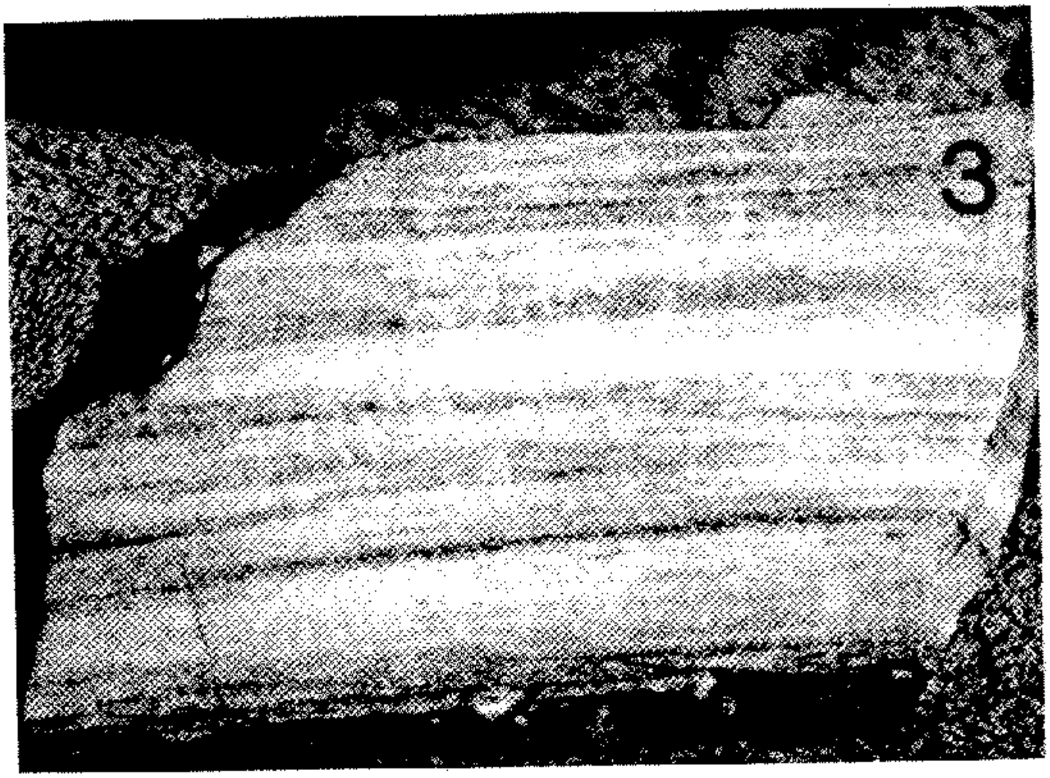

Figure 5. As deformation proceeds, or is locally more intense, layering becomes indistinct. The fine grained dolomite becomes enmeshed in the gypsiferous matrix and a mylonitic texture is apparent. Size of sample is 13 cm × 8 cm. NUMBER ON SAMPLE DOES NOT REFER TO FIGURE NUMBER.

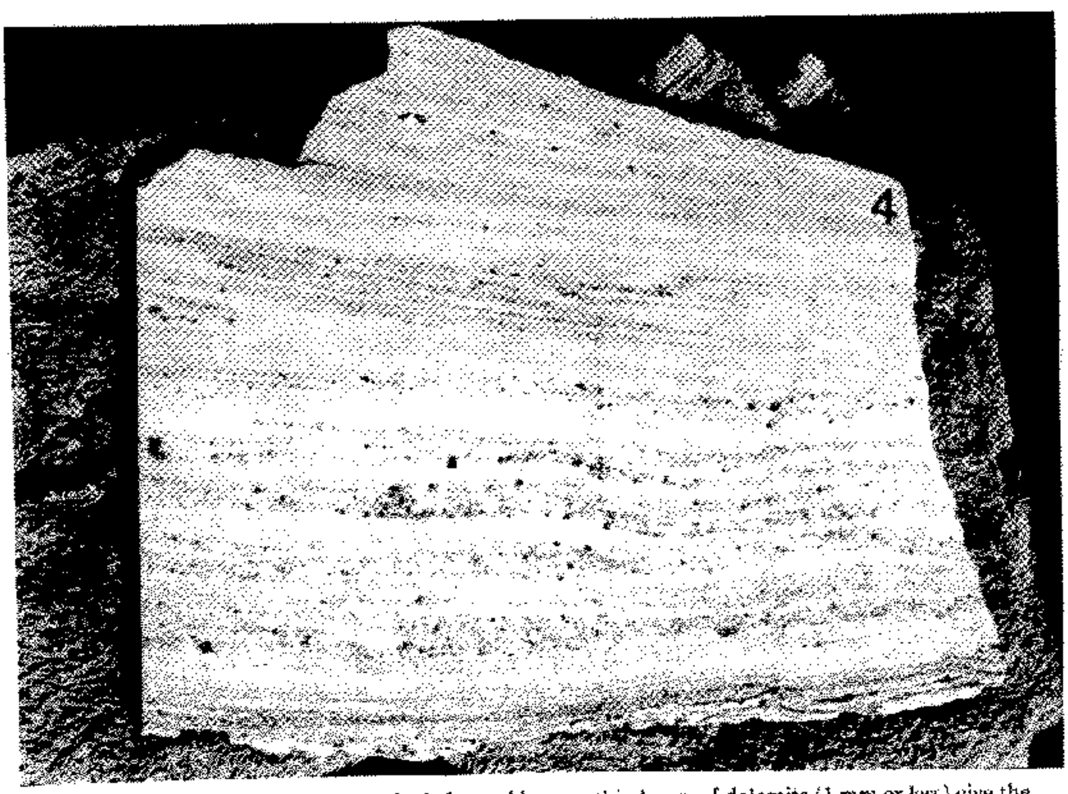

Figure 6. Recumbent isoclinal folds formed by very thin layers of dolomite (1 mm or less) give the appearance of crossbedding. Also visible are fractured and rotated fragments of dolomite. Size of sample is 21 cm × 17 cm. NUMBER ON SAMPLE DOES NOT REFER TO FIGURE NUMBER.

Castrozza illustrate the fracturing and rotation of dolomite fragments as well as the attenuation of dolomite layers (Figure 7). This location is one in which deformation appears to have been particularly intense. A comparable sample from the town of Lozzo di Cadore shows the same features (Figure 8). Lozzo is near the center of the basin where the thickness of the Bellerephon Formation is thought to be greater than 500 meters (Bosellini and Hardie, 1973) and deformation is particularly evident.

Similar features are also seen on a larger scale. Augen-like features are common in the outcrop at Lozzo and in the gypsum quarry of Comeglians, which is located 50 kilometers to the east. In these locations augen on the order of 8 to 15 centimeters in diameter are found (Figure 9). These features are generally found as isolated forms within a thick mass of gypsum. Throughout this gypsum matrix finely disseminated dolomite is generally present.

DISCUSSION

The Dolomite Mountains, or Southern Alps, are considered to be atypical of the Alpine Mountain chain (Rutten, 1969). The highly folded allochthonous terrains found in the Helvetic and Pennide nappes are not found in the Dolomite Mountains. Rutten (1969) describes the Southern Alps as (par)autochthonous with a relatively "quiet" tectonic style. This description stands in contrast to the condition of many of the evaporite exposures found in the Bellerephon Formation. The nature of the features we have described and their ubiquity strongly suggest that although the tectonic style may be quiet the structural history of the area is anything but that.

The role and importance of evaporites in tectonic processes is well known (Heard and Rubey, 1966; Müller and Briegel, 1978; Müller et al., 1981; and many others). The Jura Thrust is a prime example that is commonly cited to illustrate the role that evaporites play in thrust faults. Heard and Rubey (1966) refer to this and many other examples, although their interpretation emphasizes the high fluid pressures that may develop as a result of the gypsum-anhydrite transition rather than the low strength of these rocks. They postulated that the water liberated in the process acts as a glide plane lubricant. However, at the depths at which decollement occurred, most gypsum had already converted to anhydrite; hence this point is not considered here.

The evaporites of the Bellerephon Formation exhibit a variety of textures and features which formed as a result of tectonism. The differential response of gypsum (anhydrite at depth) and of dolomite is clearly seen. The brittle behavior of dolomite when it is stressed can be contrasted to the ductile behavior of the sulfate. The relative ease with which anhydrite will deform has been demonstrated experimentally by Müller and Briegel (1978) and Müller et al. (1981). At geologically reasonable strain rates of 10^{-14}/second, fine grained anhydrite weakens rapidly between temperatures of 150° and 200°C. At the same strain rate, sam-

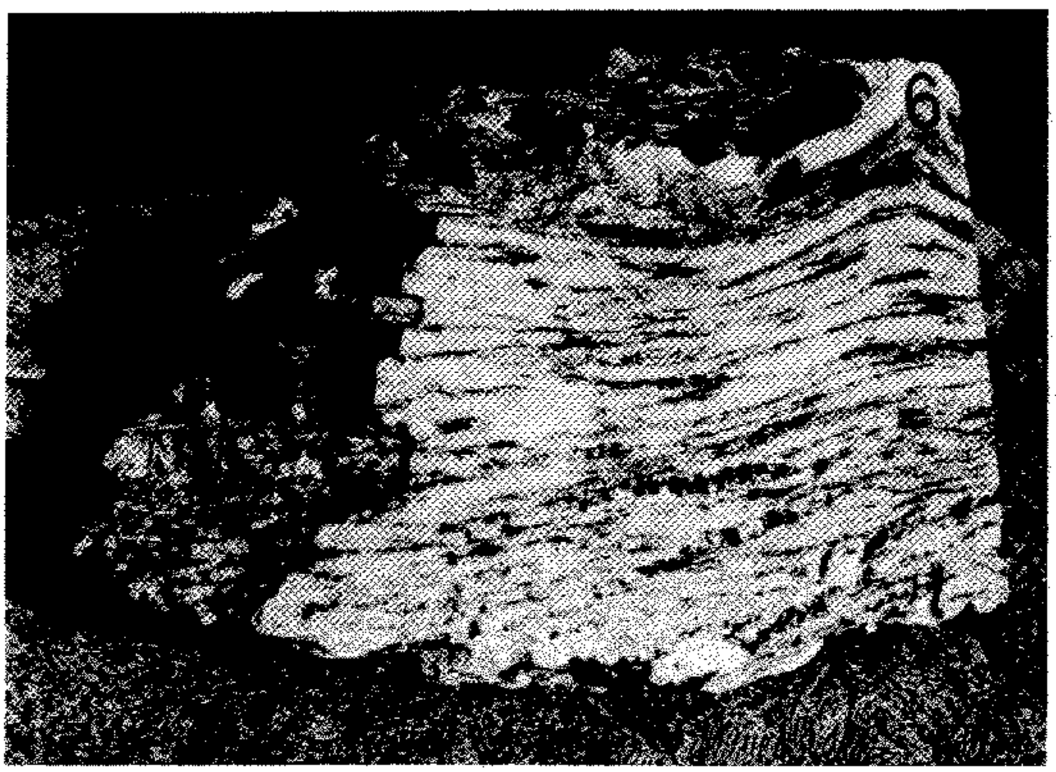

Figure 7. Attenuated layers of dolomite and fractured and rotated dolomite fragments are visible in this sample. The behavior of the dolomite is more brittle than that of the gypsum. Size of sample is 14 cm × 10 cm. NUMBER ON SAMPLE DOES NOT REFER TO FIGURE NUMBER.

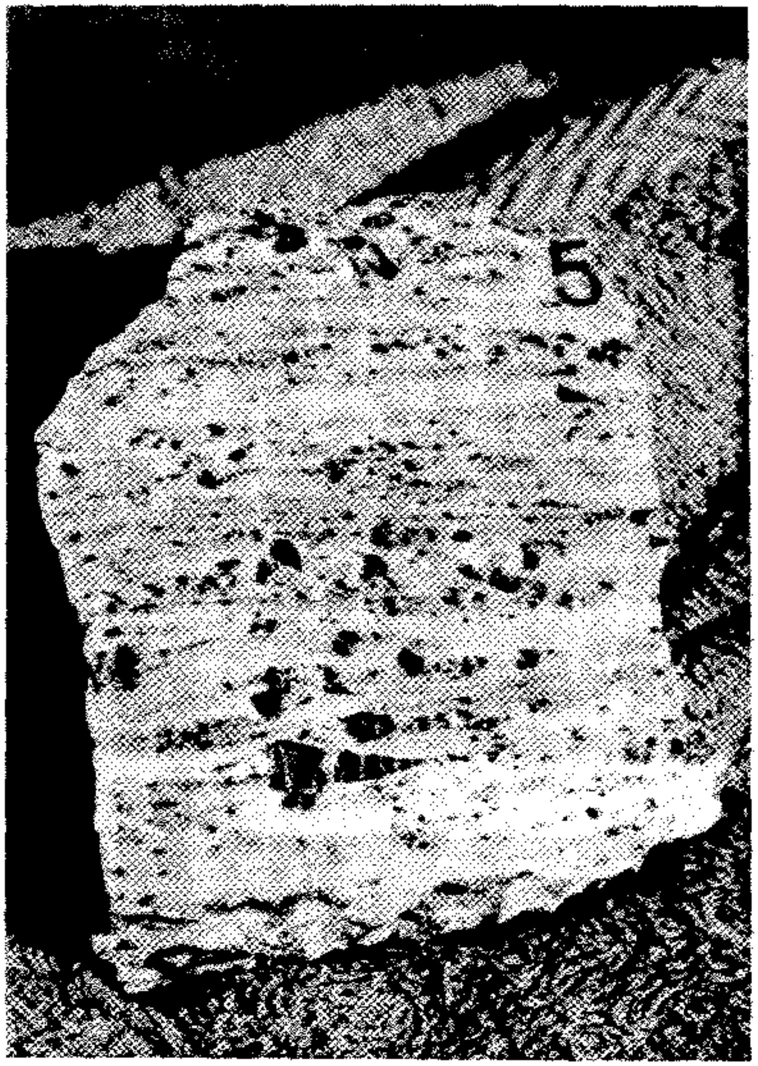

Figure 8. The contrasting behavior of dolomite (brittle) and gypsum (ductile) is clearly seen. Size of sample is 9 cm × 8 cm. NUMBER ON SAMPLE DOES NOT REFER TO FIGURE CAPTION.

ples of the Solenhofen limestone did not weaken until temperatures were between 300° and 400°C.

In many of the sections that we have examined, the thinnest dolomite beds appear to have behaved in a somewhat ductile manner. This is most likely a result of several factors, including, but not necessarily limited to, grain size of the anhydrite, thickness of dolomite layers vs. anhydrite layers, total amount of sulfate present and variation in strain rate. In general, the ductile behavior of the sulfate stands in stark contrast to the more brittle behavior of the dolomite.

The stratigraphic sequence above the Bellerephon Formation extends through the Mesozoic and into the Cenozoic. The thickness of the sequence would result in a burial depth between 4 and 6 kilometers. A geothermal gradient of 30°C/kilometer would place the Bellerephon evaporites well within the range of temperatures within which anhydrite could easily be deformed before their initial uplift during (?) Plio-Pleistocene time (Rutten, 1969).

All of the features seen in the Bellerephon Formation are known from other evaporite sequences. Rotated and fractured dolomite fragments are prominent in the deformed anhydrite of the Mokka Fiord Diapir (Otto Fiord formation), Axel Heiberg Island, Northwest Territory, Canada. Structures comparable to those described are also found in the Overthrust Belt of the Rocky Mountains, Utah (R. Lindsay, personal communication) and in the Jurassic of the same region (Picard, 1980).

Such features are not always present in all folded evaporite sequences. The deformation evident in the Permian anhydrite of Texas and New Mexico (Castile formation) was recognized only after detailed structural analysis (Kirkland and Anderson, 1970). The extreme deformational features found in the Permian of the Dolomites are not found in the Castile Formation. It should also be noted that original sedimentary structures may be preserved in areas that have undergone severe deformation. Enterolithic folds have been beautifully preserved near the Rifugio

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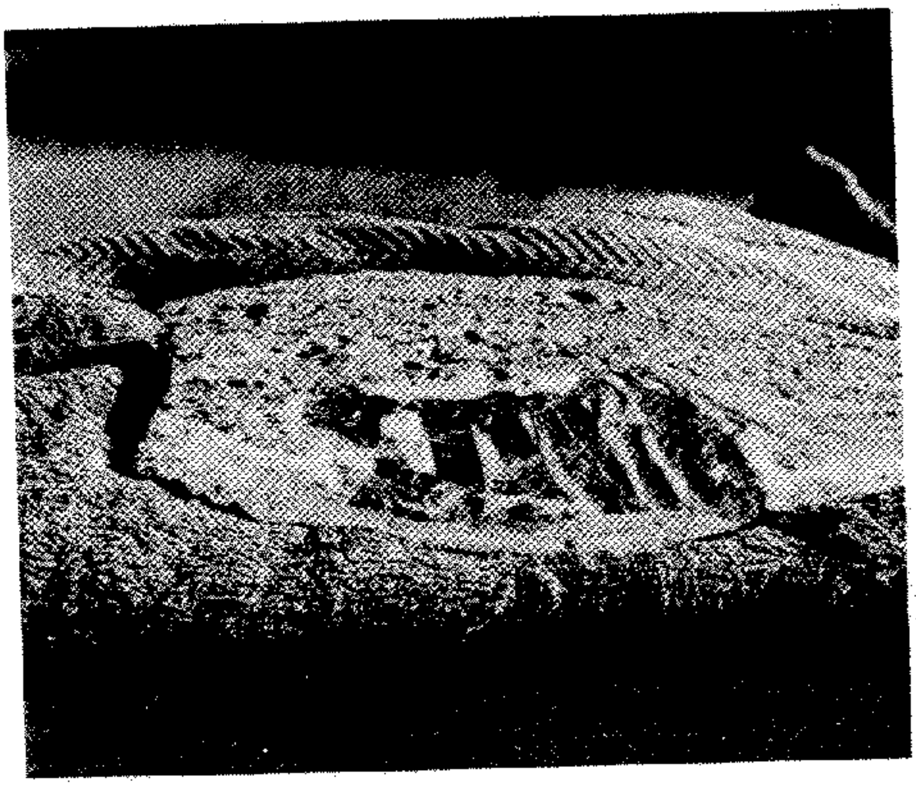
Figure 9. All photos a), b) and c) show augen-like features of various sizes. The contrasting behavior of dolomite and gypsum are clearly evident. Size of augen in c) is 14 cm × 6 cm.



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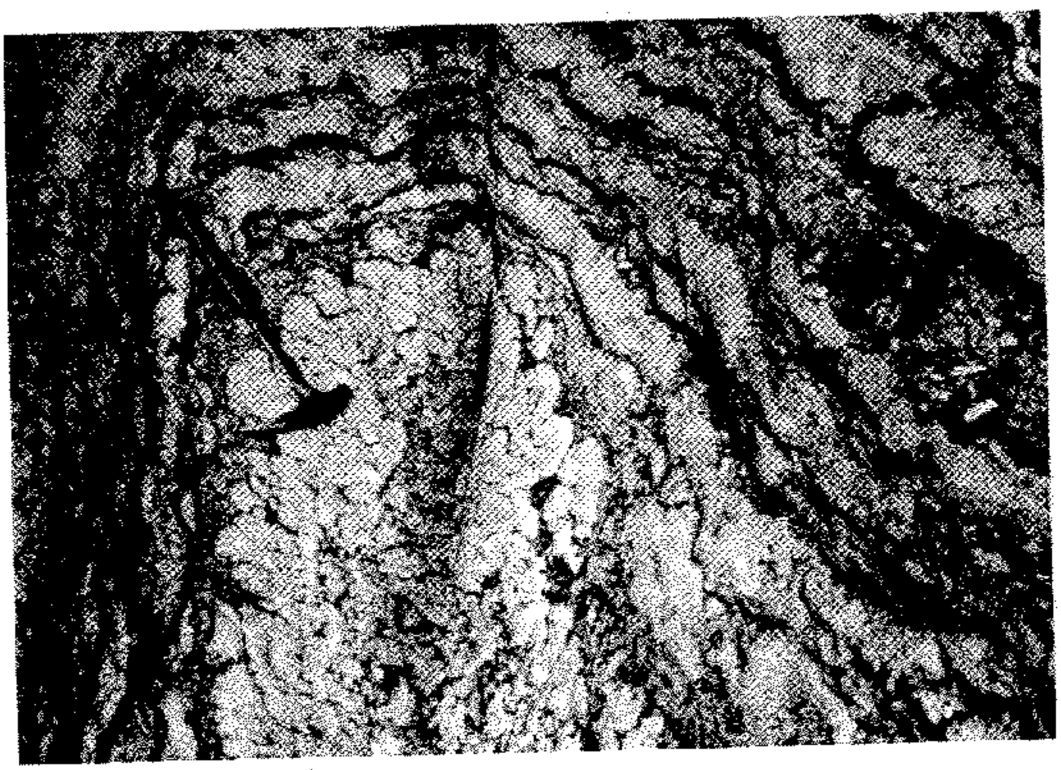

Figure 10. In this tightly folded sequence entrolithic folds (typical of sabkha evaporites) are beautifully preserved. All features described in this paper, with the exception of augen, are found closely associated with this sequence.

Flora Alpina near the town of Falcade in rocks that have suffered extreme folding (Figure 10). This outcrop also exhibits many of the features of deformation previously described, including bedding-parallel isoclinal folds, attenuation of dolomite layers, and fragmentation and rotation of dolomite.

The presence of such deformation features provides a double benefit. They offer insight into the tectonic history by giving an indication of the conditions under which deformation occurs, and they permit the separation and unraveling of poorly understood textural features, many of which obscure the sedimentological history of an area. Interpretation of such ancient evaporite sequences then becomes a matter of evaluating the enclosing sedimentary package more than the evaporite unit itself. More importantly, this study indicates the care required in the interpretation of seemingly undeformed evaporites so that structural response is not confused with original sedimentary features.

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REFERENCES

Bosellini, A. and L. Hardie. 1973. Depositional theme of a marginal marine evaporite. Sedimentology v. 20:5–27.

Dean, W. E., G. R. Davies and R. Y. Anderson. 1975. Sedimentological significance of nodular and laminated anhydrite. Geology v. 3:367–372.

Evans, R. 1967. The structure of the Mississippian evaporite deposit at Pugwash, Cumberland County, Nova Scotia. Economic Geology v. 62:262–273

Handford, C. R., R. G. Loucks and G. R. Davies (eds.). 1982. Depositional and Diagenetic Spectra of Evaporites—a Core Workshop. SEPM Core Workshop No. 3, Calgary, Canada, 395 pp.

Heard, H. C. and W. W. Rubey. 1966. Tectonic implications of gypsum dehydration. Geol. Soc. Am. Bull. v. 77:741–760.

Hobbs, B. E., W. D. Means and P. F. Williams. An Outline of Structural Geology. John Wiley and Sons, Inc., New York, 571 pp.

Kendall, A. C. 1979a. Continental and supratidal (sabkha) evaporites, in R. G. Walker (ed.), Facies Models. Geoscience Canada Reprint Series 1, pp. 145–157.

Kendall, A. C. 1979b. Subaqueous evaporites, in R. G. Walker (ed.), Facies Models. Geoscience Canada Reprint Series 1, pp. 159–174.

Kirkland, D. W. and R. Y. Anderson. 1970. Microfolding in the Castile and Todlito evaporites, Texas and New Mexico. Geol. Soc. Am. Bull. v. 81:3259–3282.

Loucks, R. G. and M. W. Longman. 1982. Lower Cretaceous Ferry Lake Anhydrite, Fairway Field, East Texas: product of shallow-subtidal deposition, in Handford, C. R., R. G. Loucks and G. R. Davies (eds.), Depositional and Diagenetic Spectra of Evaporites—a Core Workshop. SEMP Core Workshop No. 3, Calgary, Canada, pp. 130–173.

Maiklem, W. R., D. G. Bebout and R. P. Glaister. 1969. Classification of anhydrite—a practical approach. Bull. Can. Pet. Geol. v. 17:194–233.

Martinez, J. D. 1974. Tectonic behavior of evaporites, in Alan H. Coogan (ed.), Fourth International Symposium on Salt, Northern Ohio Geological Society v. 1:155–168.

Müller, W. H. and U. Briegel. 1978. The rheological behaviour of polycrystalline anhydrite. Eclog. Geol. Helv. v. 71/2:397–407.

Müller, W. H., S. M. Schmid and U. Briegel. 1981. Deformation experiments on anhydrite rocks of different grain sizes: rheology and microfabric. Tectonophysics v. 78:527–543.

Picard, M. D. 1980. Stratigraphy, petrography and origin of evaporites in Jurassic Arapien shale, central Utah. Utah Geol. Assoc. 1980, Henry Mountains Symposium, pp. 129–150.

Rutten, M. G. 1969. The Geology of Western Europe. Elsevier Pub. Co., Amsterdam, 520 pp.

Schreiber, B. C. 1978. Environments of subaqueous gypsum deposition, in W. E. Dean and B. C. Schreiber (eds.), Marine Evaporites, SEPM Short Course Notes No. 4, pp. 43–73.

Schreiber, B. C. and A. Decima. 1975. Sedimentary facies produced under evaporitic environments: a review. Special Volume: Messinian Seminar, Erice, Italy.

Schreiber, B. C., M. S. Roth and M. H. Helman. 1982. Recognition of primary facies characteristics and the differentiation of these forms from diagenetic overprints, in C. R. Handford, R. G. Loucks and G. R. Davies (eds.), Depositional and Diagenetic Spectra of Evaporites—a Core Workshop. SEPM Core Workshop No. 3, Calgary, Canada, pp. 1–32.

Wall, J. R., G. E. Murray and G. T. Diaz. 1961. Geological occurrence of intrusive gypsum and its effect on structural forms in Coahuila marginal folded province of Northeastern Mexico. A.A.P.G. Bull. v. 45:1504–1522.