toward the ordinary chlorites. Neither mineral is represented by the Tschermak formula. X-ray photographs of chamosite are constant in pattern and closely resemble those of cronstedtite. Daphnite and thuringite give patterns identical with those of clinochlore but the spacings are slightly different. The two minerals studied are distinct varieties of chlorite. Chemical analyses are by Mr. C. O. Harvey and X-ray measurements by Mr. F. A. Bannister.

(6) "The identity of zinckenite and keeleyite." By Mr. G. Vaux and Mr. F. A. Bannister.

Zinckenite from Wolfsberg, Harz, and keeleyite from Oruro, Bolivia, were compared by means of single crystal X-ray photographs about the c axis, and were found to be identical. No twinning was discovered in zinckenite which was found to be truly hexagonal with a 44·06, c 8·60Å, space-group $C^6_6 = C6_3$ or $C^2_6 = C6_3/m$.

(7) "A chemical and optical study of a low-grade actinolitic amphibole from Coronet Peak, Western Otago, New Zealand." By Mr. C. Osborne Hutton.

The chemical analysis and optical constants of an actinolitic amphibole from a low-grade albite-epidote-actinolite-chlorite-calcite-schist are given. It is shown that the maximum ext. angle in the prism-pinacoid zone is not to be obtained on a clinopinacoidal section. Details of a rare amphibole comparable with crossite in its optical properties are also given.

(8) "An X-ray examination of mordenite (ptilolite)." By Messrs. C. Waymouth, P. C. Thornley, and W. H. Taylor.

Specimens of the fibrous zeolite mordenite (ptilolite) have been examined by X-ray methods, and the specific gravity and pyroelectric properties determined. Laue- and oscillation-photographs indicate that the structure possesses orthorhombic symmetry, and the unit cell with axes $a = 18{\cdot}25$Å, $b = 20{\cdot}35$Å, $c = 7{\cdot}50$Å, contains four molecules of composition $(Ca,K_2,Na_2)Al_2Si_{10}O_{24}.7H_2O$. The space group is D_{2h}^{17} — Cmcm or C_{2v}^{12} — Cmc; the pyroelectric tests are somewhat inconclusive but indicate that the c-axis [001] is probably polar. The structure is probably based on a framework of linked tetrahedra.

CORRESPONDENCE.

THE PURBECK BROKEN BEDS.

Sir,—In a recent paper [1] the origin of the well-known Broken Beds of the Lower Purbeck of Dorset has been ably discussed. Dr. W. J. Arkell presents adequate reasons for rejecting the contemporaneous collapse hypothesis of Osmund Fisher which linked the brecciation with the decay of underlying vegetation, and in claiming a wholly tectonic origin for these curious beds has made out a strong case for the existence of tectonic factors in the determination of their present arrangement. But is his explanation of

[1] Arkell, W. J., "Three Tectonic Problems of the Lulworth District: Studies on the Middle Limb of the Purbeck Fold," *Quart. Journ. Geol. Soc.*, xciv, 1938, 1–54.

their brecciation and of their restriction to one horizon adequate? This restriction over 14 miles of outcrop is a very striking fact and, as Dr. Arkell says, "at first sight it is rather surprising that the yield took place in these beds." Is it possible that due significance has not been given to some other factor? I refer particularly to the possible former presence of gypsum (or anhydrite) at this horizon and to the effects which the hydration of interbedded anhydrite and the solution of gypsum could have had on these thinly laminated sandy limestones (note the lithology).

Recently in preparing a new edition (in collaboration with Dr. R. L. Sherlock) of the Survey Memoir on Gypsum and Anhydrite I had occasion to consider the gypsum-anhydrite occurrences in the Lower Purbeck of Southern England. As is well known, gypsum occurs at or near the base of the Lower Purbeck in Kent and Sussex in the form of massive beds, as nodular masses, and disseminated in shales, and is associated with *finely laminated sandy limestones* and cement-stones. It is worked on a considerable scale at the Sub-Wealden Mine near Robertsbridge in Sussex and has been recorded from deep borings for coal at Penshurst, Pluckley and near Battle. Significant features of the records of these borings are the frequent reference to extensive slickensiding in the shales and clays of the Purbecks (and to a less extent in the overlying Wealden) and to the occurrence of brecciated, and crumpled and broken beds of limestone at or above the gypsiferous horizon.

In the memoir dealing with the strata proved in these borings [1] it is stated on p. 72 that "The local crumpling with partial brecciation of the bedding-planes, noted in the Lower Wealden strata, was often still more strongly marked in the Purbecks, increasing in intensity downwards until its maximum was reached in the gypsiferous beds forming the base of the Purbecks."

It seems highly probable that these disturbances are due, as the authors of the memoir thought,[2] to changes in the gypsiferous beds, and here I would include the hydration of anhydrite as well as the solution and redeposition of gypsum.

We must, however, turn to areas where the calcium sulphates have been dissolved for a true appreciation of the effects that can be produced. Among the variety of breccias at the outcrop of the Magnesian Limestones of Durham there are excellent examples of brecciation believed to be due to internal rearrangement associated with the hydration of anhydrite and the solution of gypsum [3] that were formerly present and are known to occur in the limestone at depth. Here, it may be noted, Professors Hickling and Holmes

[1] Lamplugh, G. W., and Kitchin, F. L., "On the Mesozoic Rocks in some of the Coal Explorations in Kent," *Mem. Geol. Surv.*, 1911.

[2] Op. cit., p. 74.

[3] Hickling, G., and Holmes, A., "The Brecciation of the Permian Rocks," *Proc. Geol. Assoc.*, xlii, 1931, 252–5.

consider the breccias to have been derived "from a *thin-bedded or laminated and fine grained deposit* (the italics are mine) the fragmentation of which appears has taken place in situ" and they regard a deposit consisting of alternating laminae of dolomite and anhydrite as the possible original deposit.

H. B. Woodward, though advocating the tectonic rather than the collapse theory for origin for the Broken Beds, notes [1] that "In sandy limestones or calcareous sandstones belonging to the Northampton Sand, a somewhat similar appearance [to the Broken Beds] has been locally produced by the removal of calcareous matter by carbonated water. In this way some of the overlying strata have lost support and become 'Broken Beds'".

In the Lower Purbecks of Dorset large botryoidal masses of gypsum in the marls some distance above the Broken Beds were formerly worked at Durlston Bay. Indications of the former existence of salines are found in the records of salt pseudomorphs and possibly also in the presence of hard "brecciated limestone" above the gypsum horizon in Durlston Bay, and the occurrence of honeycomb limestone.[2]

Recent deep borings at Portsdown and Henfield have proved considerable beds of anhydrite in the Lower Purbecks[3], in both cases in the lower part and principally at the base of that formation, thus providing further evidence of the widespread occurrence of anhydrite and/or gypsum at the horizon of the Broken Beds.

While not questioning the presence of structures due to differential movements of tectonic origin in the Broken Beds, it seems desirable to add that if hydration of the anhydrite in a series of interbedded limestone-anhydrite beds occurred under moderate load, the 60 per cent increase in volume involved in the change from anhydrite to gypsum, might, if under pressure, the direction of which corresponded with that which produced the folding, lead to the formation of minor folds and even overfolds restricted to the belt of interbedded strata and having a direction corresponding to the regional strike.

Whatever the merits of the latter possibility it is suggested on the basis of the above facts that anhydrite was formerly present at the horizon of the Broken Beds and that its hydration and the subsequent solution of the gypsum were contributary factors in the formation of the Broken Beds.

S. E. Hollingworth.

Geological Survey and Museum.
8th April, 1938.

[1] "The Jurassic Rocks of Britain," vol. v; "The Middle and Upper Oolitic Rocks of England," *Mem. Geol. Surv.*, 1895, p. 248.

[2] Bristow, H. W., Vertical Sections, Geol. Surv., Sheet 22.

[3] Lees, G. M., and Cox, P. T., "The Geological Basis of the Present Search for Oil in Great Britain by the D'Arcy Exploration Company, Limited," *Quart. Journ. Geol. Soc.*, xciii, 1937, 177, 180.

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Sir,—I am much indebted to Dr. Hollingworth for sending me his interesting and constructive remarks and for giving me the opportunity to comment upon them.

(1) The Permian breccias described by Hickling and Holmes do not afford a satisfactory analogy because they lack the dip-and-strike structures of the Dorset breccia, as was pointed out in my paper (op. cit., p. 17). The argument that carries most weight to my mind, however, is that numbered (6) in my paper (p. 19), namely that the 14½ miles of outcrop in which the Broken Beds are developed coincide with the middle limb of the Purbeck Fold; that the 10 miles of outcrop from Ringstead to Portisham where no Broken Beds are recorded lie in the foreland of the fold and were already separated from the middle limb by the pre-Gault erosion. It should be noted that the gap of 2¾ miles between these two regions, where the change takes place, coincides with the passing of the outcrop from the middle limb on to the foreland; and since the gap represents only about 9 per cent of the whole mainland outcrop in length, this coincidence is unlikely to be due to chance. Moreover, the Broken Beds reach their maximum development about Lulworth, where the fold is "tightest" owing to thinness of strata, although this region is nearest to the unbroken foreland. At Lulworth, too, higher beds are involved than elsewhere, the whole Cypris Freestones being violently displaced and jumbled at the Fossil Forest.

(2) If the cause of brecciation had been salts interlaminated with the thin-bedded limestone, a more uniform and small-scale disintegration might have been expected. On the contrary, huge blocks from 1 to 2 feet thick are characteristic of the Lulworth Broken Beds. They are tilted but unshattered and do not show internally small-scale disturbance of the bedding such as described by Lamplugh and Kitchin in Weald boring cores.

(3) That previous expansion or removal of salts may have produced a plane of weakness which was responsible for localizing the differential movements at this horizon is highly probable. After reading Dr. Hollingworth's note I re-examined the Ringstead section (the first and best section on the foreland after passing westward off the middle limb), and I think enough can be seen there to support his suggestion. On a horizon corresponding with the lower part of the Lulworth Broken Beds there is for a foot or two vertically a band of puckering and obscure disturbance, and locally even small-scale brecciation, which I had been inclined to attribute to compaction against the underlying irregular tufas, enhanced by a certain amount of differential movement during the intra-Cretaceous folding, in which the beds were tilted to 35 degrees. This may well indicate a horizon at which anhydrite has changed to gypsum and then been removed, and such a plane of weakness might have determined the level at which the subsequent differential

sliding took place in the Lulworth district and Purbeck. I would therefore add this possible cause of the localization of movement to the two suggested in my paper (p. 21). Probably the three causes combined to produce the present remarkable effects when the Tertiary folding set the rocks in motion.

W. J. ARKELL.

THE AGE OF THE ELSWORTH ROCK.

SIR,—Dr. Spath's change of ground is bewildering. In his first letter he claimed to have anticipated my conclusions. In his second letter, unable, when challenged, to produce the references or justify his charges, he applies himself to destroying the conclusions. In the well-known manner of S. S. Buckman he splits up the stratigraphical units and refers mysteriously to missing foreign faunas. By this means doubt can be cast on any correlation.

Study in recent years of Corallian ammonites in museums from the west of France to Berlin and from Scotland to the Rhone Valley, combined with a little collecting, has convinced me that our Corallian Beds are very well representative (except in the upper parts not germane to this discussion), and that broad zones such as I use are all that there is scientific basis for using. I have not heard from those in charge that Dr. Spath has examined any of these collections. To assert an opinion, still more assume superior knowledge, without doing so is unjustifiable. The literature and foreign material in this country are far too meagre. Dr. Spath, moreover, has much field work to do before he can show the inapplicability of these zones in England.

With regard to the new subject raised by Dr. Spath, concerning the types of *Am. serratus* Sow. and *Am. cordatus* Sow., the course I have taken is that which involves least alteration of the usage of the last century or more. In the case of *Am. serratus* I have upheld the conclusion of the reviser, Salfeld, against a subsequent reversal by Dr. Spath (although from the latter's sentence, containing the words "chaos" and "gratuitous alteration", the reader derives just the opposite meaning). *Am. cordatus* is more complicated and there has yet been no reviser. As the matter will be discussed with full documentation in my monograph I need not encroach on your space by anticipating the account except to say that what I advocate is adherence to the interpretation of *Am. cordatus* made by the leading Jurassic palaeontologists and stratigraphers of several generations, so that it can continue to be used as index fossil for the Cordatus Zone, one of the first to be named (in 1852) and constantly recurring in world literature ever since.

W. J. ARKELL.

UNIVERSITY MUSEUM,
OXFORD.
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