genetic comparisons of closely-related species or populations of a single species. Differences between vertebrates and invertebrates are too many and too intangible to be valuable in this type of comparison.

VAN DER WAALS

Honoured Again

from our Statistical Mechanics Correspondent

VAN DER WAALS'S own university of Amsterdam celebrated the centenary of the publication of the famous equation by organizing a conference on statistical mechanics (under the auspices of the International Union of Pure and Applied Physics) which took place between August 26 and 31. It was on altogether a larger scale than the Centenary Conference held at the University of Kent in April (see *Nature*, **243**, 263; 1973), the programme of which was practically confined to liquids and critical phenomena.

The main emphasis of the conference was on the fields opened up by van der Waals—the equation of state, corresponding states and scaling laws, mixtures and surface tension. It was possible to hear all the invited papers (if not all the contributed ones), which should retain their interest as surveys for many years to come. One was continuously reminded that science almost never advances in the clean and tidy way that might be imagined from a superficial reading of its history.

For example, J. de Boer (University of Amsterdam) and M. J. Klein (Yale University) showed what a gross error it would be to say that van der Waals simply used some then current ideas to give a nice interpretation of the work of Andrews. In fact, van der Waals's real roots go back to Laplace and Newton. J. M. H. Levelt-Sengers (US National Bureau of Standards) recalled that discrepancies between experiment and the van der Waals critical exponents were known in 1900, but had to wait until 1965 for a satisfactory interpretation. Scaling laws and their possible origins were discussed by B. Widom and K. G. Wilson (both of Cornell University). J. L. Lebowitz (Yeshiva University) showed that the equilibrium van der Waals equation can now be rigorously derived, but that serious doubts remain about the metastable regions of the van der Waals loop, which were also discussed by J. S. Langer (Carnegie-Mellon University).

Difficulties become even more severe when attempting to discuss apparently simple transport phenomena in a fluid, as was shown by P. M. Résibois (Free University, Brussels) and by B. J. Alder (University of California, Livermore). R. B. Griffiths (Carnegie-Mellon University) discussed the new phenomenon of a "tricritical point" that occurs with mixtures, E. M. P. Guyon (University of Paris, Orsay) described instabilities in liquid crystals and E. B. Smith (University of Oxford) surveyed present knowledge of intermolecular potentials, the raw material of theory. Exactly soluble models of phase transitions were reviewed by E. H. Lieb (Massachusetts Institute of Technology) and melting, obviously a much more complicated phenomenon than evaporation, was dealt with by H. Mori (Kyushu University); this last contribution provoked a lively, but quite friendly, discussion. J. van Kranendonk (University of Toronto) showed what detailed information is now available from spectroscopy about mechanisms of collision, induced dipole moments and the formation of bound complexes.

A sad note was struck by the contribution on specific heats by A. V. Voronel (USSR) (read in his absence by C. Domb) which called attention to the difficulties caused by gravity (not fully appreciated until the 1950s), the necessity for stirring and surprisingly that, from the point of view of deriving critical exponents from experimental results, it can matter very much which of several possible alternatives one chooses as the definition of the "order parameter".

OPHIOLITES

Troodos as Arc Volcano

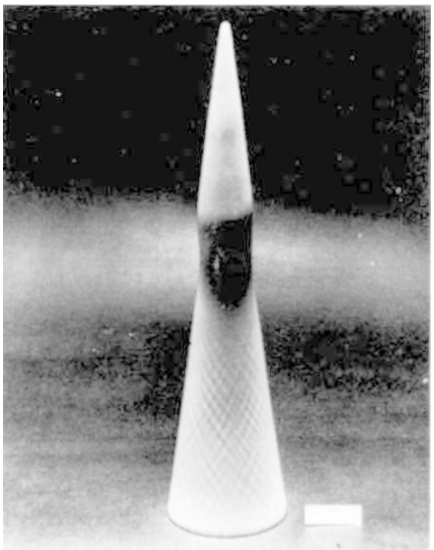
from our Geomagnetism Correspondent

THE search for evidence to support the idea that the Troodos Massif of Cyprus is an upthrust fragment of ancient ocean floor has been going on for more than a decade. During this period there have been several individual disappointments and setbacks, although the chief problem has been not so much the unwelcome discovery of evidence conflicting with the ocean floor hypothesis but the inability to obtain data giving unequivocal support. As a result, the hypothesis has had few, if any, active opponents, and most people with an interest in the situation have been content either to suspend judgment or to accept the circumstantial evidence.

But this happy consensus has now been broken by Miyashiro (*Earth planet. Sci. Lett.*, **19**, 218; 1973), who argues against one of the basic concepts involved. The Troodos Massif is, of course, an ophiolite complex; and in recent years it has come to be accepted, at least by supporters of plate tectonics, that ophiolite complexes were formed at oceanic ridges. Miyashiro, however, has carried out an analysis which, he claims, shows that the Troodos rocks are chemi-

Turbulent Gas Flows on the Moon

THE idea that surface markings on some parts of the Moon were produced by supersonic turbulent gas flows is re-examined in next Monday's *Nature Physical Science* (September 24) by Rehfuss and Larson. It has been previously thought that these lineations were produced by outgassing; recent work by Rehfuss, however, pointed to an association with gas produced in vaporization during meteor impacts (*J. geophys. Res.*, **77**, 6303; 1973). The second possibility now seems to be supported by a pattern of cross-hatching found at Silver Spur, a feature near the Apollo 15 landing site.



Cross-hatching ablation pattern on teflon surface produced during tests at Marshall Space Flight Center.

Diamond shaped patterns, or cross-hatching, are a common feature of wind tunnel ablation studies (see figure) and are also found on recovered flight vehicles. Such patterns also occur on the Moon, notably where two sets of lineaments intersect about 20 km south of the Apollo 15 landing site, suggesting strongly that the area has experienced supersonic turbulent flow. Such a flow can be produced in the expanding gas cloud which forms when a meteorite strikes the Moon at a speed above 16 km s^{-1}, regardless of the size of the meteorite.

Clearly, if the model is correct then there should be a young crater near to the Silver Spur cross-hatching. Rehfuss and Larson discuss the plausibility of the candidature of several nearby craters, and suggest that the best possibilities are Aristillus, Autolycus and Aratus. If any of these three craters was produced by a meteorite impacting at sufficiently high speed the impact could have produced the required turbulent flow at Silver Spur.

cally distinct from those produced at oceanic ridges and more closely resemble the volcanic piles in immature island arcs with relatively thin oceanic-type crust. In other words, he proposes that the Troodos Massif was created as a volcano in an island arc between Eurasia and Africa.

The chemical basis of Miyashiro's analysis is the variations of the ratio FeO*/MgO (an increase in which is a measure of the advances in fractional crystallization of basaltic magma) with FeO*, SiO_2 and TiO_2—variations which enable distinctions to be made between the tholeiitic series and the calc-alkalic series of igneous rocks. For example, when SiO_2 is plotted against FeO*/MgO over the approximate FeO*/MgO range 2–5, the rate of increase in the SiO_2 content as fractional crystallization progresses is found to be much lower for tholeiites than for calc-alkalic rocks, and a definite dividing line may be perceived between the low gradient tholeiitic rocks and the higher gradient calc-alkalic rocks. This distinction is even more convincingly demonstrated by the variations of FeO* with FeO*/MgO. As fractional crystallization proceeds in tholeiitic rocks the FeO* content rises to a maximum and then decreases; in calc-alkalic rocks, by contrast, FeO* decreases monotonically. A similar pattern is also observed for the variation of TiO_2 with FeO*/MgO. Moreover, these trends are apparently altered very little by metamorphism or other secondary processes.

The relevance of these distinctions to the Troodos Massif is that certain of the Massif rock compositions fail to fall into the group expected on the basis of an origin at oceanic ridges. Most, if not all, non-alkalic igneous rocks from the deep ocean floor are known to be tholeiitic. Whether or not there are any calc-alkalic rocks of genuine ocean floor origin is still a moot point, but if there are, the results of dredging suggest they must be very rare. Plots of SiO_2, FeO* and TiO_2 against FeO*/MgO for samples of the lower pillow lavas and the sheeted complex from the Troodos ophiolite sequence show, however, that a relatively high proportion follow the calc-alkalic trends described earlier. The data points are quite widely scattered; and there can be no doubt that many of them represent tholeiitic rocks as expected. But for about one-third of the samples, SiO_2 increases rapidly and FeO* and TiO_2 decrease rapidly with increasing FeO*/MgO in accordance with calc-alkalic behaviour.

The implication of the presence of such a high proportion of calc-alkalic rocks is that the Troodos Massif is unlikely to have been created at an oceanic ridge. Moreover, on the more positive side, a relative abundance of calc-alkalic rocks is more in keeping with volcanism in island arcs and continental margins, as Miyashiro himself recently showed (*Am. J. Sci.*, **272**, 629; 1972). And to make his case even stronger, Miyashiro points to a possible modern analogue of Troodos. Hachijo-jima is a small volcanic island in the northern Izu-Bonin Arc; and the FeO*, SiO_2 and TiO_2 plots for its rock compositions bear a remarkable resemblance to the corresponding Troodos plots. The chief difference is a smaller proportion of calc-alkalic rocks on the island. In other words, in Hachijo-jima there is a volcano, demonstrably produced in an island arc environment, yet having a less developed calc-alkalic series than in a supposed segment of old oceanic floor where the occurrence of calc-alkalic rocks is theoretically unlikely.

But what of other geochemical work that has been taken to support the concept of Troodos as oceanic crust? Kay (*Eos*, **53**, 536; 1972), for example, claimed that the rare earth element abundance patterns from Troodos igneous rocks resemble those from abyssal tholeiites. Miyashiro's reply to this, quoting Schilling (*Phil. Trans. R. Soc.*, **A268**, 663; 1971) as authority, is that the patterns from island arc tholeiites also resemble those from abyssal tholeiites—and so Kay's data are also consistent with the concept of Troodos as island arc volcano. A similar consistency is claimed for the Ti, Zr and Y abundances reported by Pearce and Cann (*Earth planet. Sci. Lett.*, **12**, 339; 1971).

Finally, as Miyashiro recognizes, one of the arguments in favour of Troodos being oceanic crust is the presence of dyke swarms (sheeted complex), interpreted as representing oceanic ridge-type crust formation. This does pose a problem in that on island arc volcanoes such as Hachijo-jima no parallel dyke swarms are observed on the surface. The deep structure of island arc volcanoes is, however, little known; and so dyke swarms may exist at depth. Moreover, a dyke swarm does not seem to be a necessary component of ophiolite complex. The Vourinos complex in northern Greece has both tholeiitic and calc-alkalic trends (again suggesting island arc formation) but no marked dyke swarm.

Benioff Slopes and Mineral Deposits

METALLOGENIC belts near both old and new consuming plate margins have been related to the underlying presence of Benioff zones. But although the models developed have incorporated Benioff zones which remain stationary or migrate oceanwards (to accommodate the production or extension of marginal basins), the zones have usually been regarded as having constant slopes. In *Nature Physical Science* next Monday (September 24), however, Mitchell argues that the slope of a Benioff zone is an important variable, governing not only marginal basin spreading and the migration of island arcs but also the nature of the deposits emplaced near continental margins.

As far as the tectonics is concerned, most island arcs overlying Benioff zones which dip at angles greater than about 35° are associated with late Cainozoic extension of the marginal basins or, more rarely, major displacement along strike-slip faults. Mitchell thus suggests that the development of marginal basins only occurs above Benioff zones with steep or moderate dip. The variation of dip from one Benioff zone to another is, however, not the only sense in which dip may be regarded as variable, for the dip of a single zone may vary with time. There is some evidence, for example, that the marginal basin spreading behind the Marianas arc is cyclic, spreading only occurring when the dip is steep, and that the changes in dip are related to changes in the rate of descent of the lithosphere.

Both between-zone and within-zone variations of dip are involved in Mitchell's more important thesis, which is that the type of metallogenic belt formed at any given time depends on whether the dip of the corresponding Benioff zone is shallow or steep. Arguing from particular examples, Mitchell concludes that deposits of tin, tungsten, bismuth and fluorite and associated granites are emplaced near continental margins only above shallow-dipping Benioff zones. Porphyry copper deposits, on the other hand, are emplaced in andesitic and tonalitic rocks on continental margins and island arcs above steeply dipping Benioff zones, although they may also occur in silicic volcanic rocks above tin-bearing granites associated with shallow-dipping zones. The occurrence of copper in both types of environment suggests, however, that it might be possible to recognize two gradational types of porphyry deposit—and there is already a little evidence for this. It seems, for example, that copper-molybdenum deposits are more frequently observed in association with silicic volcanic rocks (shallow dip) and that copper-gold deposits are more common in the andesitic environment (steep dip).

Finally, this work suggests the theoretical possibility that Benioff zone models might be used to aid mineral exploration. Mitchell warns, however, that interpreting the distribution of metallogenic belts is one thing but prediction is quite another.