the effects are due to successive raising and lowering of the whole crust. If the maximum change of the outer radius be twelve feet, the thickness of the crust which must be moved vertically by this amount, in order to explain the astronomical observations, is fifty miles. If uniform expansions and contractions throughout the whole earth be assumed, the maximum change of the external radius necessary is five inches. An assumption somewhere between these extreme limits appears to be the only way of explaining the fluctuations. It will be seen at once that, while local oscillations may be present, they cannot be invoked to account for the main phenomenon.

If oscillations of the whole crust take place, a natural procedure is to search for evidence of them in terrestrial phenomena. With a crust formed of uniform and unbroken material like that which composes the surface, detection would be difficult, because the resulting strains and pressures are far within the elastic limits. From the actual crust, of unequal heights, fissured in all directions and undergoing constant change from erosion, something observable may be expected. Adjustments, especially those needed for isostatic compensation, are continually taking place, and might be expected to be more frequent with or soon after a change of radius. The interpretation given here requires the earth's radius to be below its mean value from about 1790 to 1898, and a change near this latter date from the minimum to the maximum value taking taking place within a very few years, as well as a further sudden change to the mean value about 1917. Other sudden changes may have occurred in the past, but the observations lack the accuracy needed for definite statements.

Some attempts to correlate the observations with seismic phenomena have been made. Prof. H. H. Turner some years ago deduced a period of between 200 and 300 years from the records of Chinese earthquakes, and suggested that it might be related to the lunar deviations. In this connexion it must be remembered that the curve of Fig. 1 represents nearly all our present knowledge; we do not know the extent to which the period or amplitude as deduced from this curve may represent what has taken place in earlier centuries. I have attempted a comparison with the frequency of British earthquakes from the material collected by Davison in his "History of British Earthquakes." There are indications of some correlation, but as they depend partly on the curvatures at different places of the curve in Fig. 1, there is doubt as to their reality. Correlation with the intensity of volcanic action was also briefly examined without success. The records of Kilauea as gathered by Dana and others would probably have served as a test if the material had been as complete and continuous as that gathered by Dr. Jaggar since 1911.

One remarkable correlation seems to be well founded, namely, the close correspondence between the frequency of British earthquakes on one hand and the difference between the Greenwich observations and the occultations on the other. Since the occultations are gathered from observations in widely different places and are nearly free from systematic error, it would seem that the Greenwich observations are subject to a small systematic error which depends on local earth movements. This same difference is also correlated with the lunar deviations. Closer examination of these correlations has not furnished any explanation for their occurrence.

The applications of the hypothesis, assuming that the oscillations have existed for long periods, to the formation of the surface features of the globe are far-reaching. Their source must obviously be sought in the physical and chemical conditions of the earth below the outer crust. It follows that a large supply of energy is available for external use. Adjustments to relieve the strains indirectly caused by erosion will be more frequent than without the oscillations, and the accumulated strains will be smaller. General statements of this character, however, do little more than furnish a basis for detailed investigations of specific problems. Can such oscillations, for example, constitute a factor of importance in the building of a mountain chain bordering a deep depression, as in the Pacific area? Will there be vertical or horizontal differential movements of continental areas, and, if so, can such movements be detected in variations of sea-level or of deposition of sediments? As to the latter, an inch of deposit in 200 years is 400 feet in 1,000,000 years, or 80,000 feet in 200,000,000 years, so that the magnitudes involved are of the right order for observation if the phenomenon exists. Many other questions of a similar character will occur to the geologist and the geophysicist.

The Principles of Biological Control in Economic Entomology.[1]

By Dr. R. J. TILLYARD, F.R.S., Chief of the Biological Department, Cawthron Institute, Nelson, N.Z.

I.

THE CONTROL OF INJURIOUS INSECTS.

IN considering the possibilities of success of the method of biological control of injurious insects, we have to take into account a number of factors, the most important of which are the climatic conditions and the amount of economic disturbance in the affected area. The most striking successes in control have been made in countries with a warm and equable climate, in which new beneficial insects can be introduced with greater ease and, when introduced, flourish and spread more rapidly, than in countries in which either a marked change of seasons or a severe winter has to be faced. But this climatic factor, important as it is, must rank only second to another factor, which may be termed the *amount of disturbance* of the affected

[1] From the Trueman Wood Lecture of the Royal Society of Arts, delivered on Oct. 27, 1926.

area. To illustrate this point, let me take the case of an apple orchard in Australia or New Zealand. Ecologically speaking, one is no more a part of Australia than the other is of New Zealand; both are little pieces of Old England translated to a new environment with the same plant, the apple-tree, attacked in the same manner by the same pests, codlin-moth, woolly aphis, and the rest (fortunately by no means all of them are present either in Australia or New Zealand), and the same problems of cultivation, spraying, picking, and marketing. The same is true of a dairy farm or a planted forest area of exotic pines. In all these cases, before man came on the scene, the same piece of soil presented an entirely different ecological problem, with only native plants and native animals in the picture. Thus these apple orchards, these dairy farms and forest plantations, are pieces of *disturbed country*, and the amount of disturbance might, perhaps, be mathematically expressed by a formula which would show the percentages of original plants and animals remaining on the area.

Now the crux of the whole problem, of course, is the difference between the ecological interplay of various factors in their natural habitat and in the disturbed country. Take, for example, the case of an apple orchard in New Zealand, attacked, let us say, by the woolly aphis, *Schizoneura lanigera*. The original home of this pest was North America; in many countries it is still called 'American blight.' The pest, when studied a few years ago in New Zealand, was found to be almost unbelievably virulent, and was really threatening the continuance of the apple industry. In America, on the other hand, it has never attained anything like the same degree of severity. The more favourable climate of New Zealand is evidently one of the factors making for increased severity of the pest; but the main cause of it is clearly to be seen as arising from the incomplete balance of Nature in a piece of thoroughly disturbed country. In other words, man, after destroying the original association of plants and animals on the area, had proceeded to introduce (1) the apple tree, and (2) (unwittingly of course) the woolly aphis, without balancing this association by (3) the natural enemies of the woolly aphis in the form of parasitic and predatory insect enemies.

Let us now note carefully the effect of the scientific attempt to redress this lack of balance. The task was given to me six years ago, as the most pressing problem of the moment, when I joined the staff of the newly formed Cawthron Institute in Nelson. In the course of a visit to America, undertaken with this as one of its main objects, I found that there were three kinds of insects which attacked woolly aphis successfully enough to make them worthy of consideration. These were (1) syrphid flies of the genus Pipiza, (2) the Californian ladybird beetle *Hippodamia convergens*, and (3) the chalcidoid wasp *Aphelinus mali*. In considering which of these to introduce into New Zealand, I rejected the syrphid flies because of the abundance of allied native forms in New Zealand and their inability to make headway owing to severe parasitism from Ichneumonidæ. As regards the other two insects, all the evidence seemed to point in favour of *Hippodamia convergens*. It had a wonderful record in California and was rightly regarded as one of the most valuable of known beneficial insects. Large sums of money have been spent in rearing, collecting and distributing it, and every Californian fruit-grower is fully convinced of the benefits which it confers upon him. Opinions regarding *Aphelinus mali*, on the other hand, were not so uniformly favourable. It had already been introduced into South Africa, where it was considered to be a failure. If I had had to make a choice, the evidence would have been in favour of Hippodamia. However, I was able, through the great kindness of Dr. L. O. Howard, chief of the Bureau of Entomology at Washington, D.C., to obtain good supplies of both these insects. The results were very interesting. *Hippodamia convergens* was introduced and liberated in thousands throughout the Nelson Province, but has not since been seen or heard of. It is probable that its known habit of seeking the tops of high mountains and hibernating beneath the snow has proved its undoing, for it has failed to establish itself permanently in every country into which it has been introduced. *Aphelinus mali*, on the other hand, after being kept alive with great difficulty during the first winter in New Zealand (the period corresponding with the *summer season* in North America which it should normally have experienced), became acclimatised and increased with great rapidity and vigour in the insectaries. In the course of three or four years it was distributed in large numbers to all commercial apple orchard centres in New Zealand. The result has been that woolly aphis is now under satisfactory control in New Zealand and is no longer regarded as a serious pest. The New Zealand strain of this insect has also been sent over to various parts of Australia and is proving highly beneficial there.

As regards Australia, the conditions there are very different from those in New Zealand, but I do not wish it to be thought that biological control has no future in that great country. California is part of a great continent almost as big as Australia; yet good results have been obtained there by the method of biological control. The reason is, perhaps, that California itself is really an ecological 'island,' separated from the rest of the continent by barriers of mountain and desert. If that be so, then there is great hope of successes in Australia. First of all, the whole country is an island, both geographically and ecologically, as well as a continent. Secondly, it is made up of a large number of diverse areas separated from each other, as California is from the rest of North America, by mountain barriers or great stretches of desert. Looked at from this point of view, Western Australia, for example, should provide almost as perfect a field for biological control as New Zealand, while many parts of eastern Australia, such as the elevated apple lands of South Queensland, should be ideal for application of the same methods.

I now wish to emphasise the advantages which the biological method of control has over the chemical method. First of all, control of an insect pest by spraying or fumigation is only *annual* control, not *permanent* control, and it only extends to those areas in which it is faithfully carried out. Let there be any slackening, either in place or time, of the strict spraying schedule, and the insect pests immediately take advantage of it. Further, the cost of chemical control is a continuous annual drain on the industry, whereas the cost of biological control is a definite amount, terminating when the beneficial insect has been successfully established.

I think it would be of interest to give a short account of the principal researches in biological control of insect pests which are at present being carried out in Australia, New Zealand, and Fiji.

1. *Control of Woolly Aphis*.—The New Zealand strain of *Aphelinus mali* has been sent across to all six Australian states, and is now being reared and distributed over there. Reports indicate that success is being steadily attained in Queensland and Western Australia, while in the other States the work is not sufficiently advanced to say what the result will be.

2. *Control of Pear Leaf-Curling Midge* (*Perrisia pyri*).—Mr. David Miller, Government Entomologist of New Zealand, is now engaged on the problem of introducing beneficial parasites on this bad pest. Supplies of *P. pyri* are being forwarded by the Imperial Bureau of Entomology in London, and attempts are being made to establish species of Inostemma and Platygaster known to be present. Judging by latest reports, considerable progress is being made with the species of Platygaster, and a favourable result to this important investigation may reasonably be looked for.

3. *Control of Earwig* (*Forficula auricularia*).—This insect is a very serious pest of peach and apricot orchards in the irrigation areas of Teviot and Central Otago, New Zealand. An attempt was made to introduce the parasitic tachinid flies, *Digonochœta setipennis* and *Racodineura antiqua*, through co-operation between the Imperial Bureau of Entomology, Rothamsted Experimental Station, and the Cawthron Institute, Nelson. Considerable progress was made, but the work came to an untimely end through the long illness of Mr. H. M. Altson, who had charge of the work in England. The work is now again to be taken up, and the experience gained in the previous attempt should be of great value in this very difficult problem. One great advantage which New Zealand possesses over America in this case is the absence of the secondary parasites of the tachinids. The most abundant of these, *Dibrachys boucheanus*, is already present at Portland, Oregon, where the earwig infestation is worst, and renders the problem almost hopeless so far as control by tachinid parasites goes.

Parenthetically, a curious illustration of the unforseen difficulties which arise in this highly specialised work may be here mentioned. The waxmoth, *Galleria mellonella*, is becoming a serious pest in New Zealand, and a request has been made that the Cawthron Institute should endeavour to introduce a natural enemy to check it. Now it so happens that the only parasite which appears to be at all promising is *Dibrachys clisiocampœ*, which is so closely allied to *Dibrachys boucheanus* that it must be kept out of New Zealand at all costs if the experiments in controlling earwigs are ever to succeed. Consequently either the fruitgrowers or the bee-keepers must be disappointed. I have no hesitation in deciding that the earwig is by far the worse pest of the two insects in question ; and so, if the waxmoth is to be controlled by its natural enemies, some species which will not attack the tachinid parasites of the earwig must be used instead of Dibrachys.

4. *Control of Oak Scale* (*Asterolecanium variolosum*).—This insect, never a serious pest in Europe, has become so abundant on British oaks in parts of New Zealand that it is actually killing them. The only known parasite is *Habrolepis dalmanni*, of which several consignments have been received at the Cawthron Institute from Dr. Howard. A large number of females were reared from the last consignment, and, if it turns out that this species is parthenogenetic, there will be a very good chance of establishing it and so checking the scale.

5. *Control of Introduced Aphids in General*.—Only one or two very rare native species of aphids are known in New Zealand, but there are a considerable number of injurious introduced species. One of the most curious gaps in the New Zealand insect fauna is the complete absence of the green lacewings or Chrysopidæ, which are such a valuable check on aphids in other parts of the world. An attempt is therefore being made by the Cawthron Institute to acclimatise these insects in New Zealand. A fine consignment of 1900 hibernating adults of an undetermined Canadian species has been received in excellent condition, through the kind offices of Mr. Gibson, the Dominion Entomologist of Canada, and Mr. Downes, the State Entomologist of British Columbia. Three generations have already been reared and a fair number have managed to survive the rather too warm winter of Nelson. There seems to be a reasonable prospect of the final establishment of this or some other similar species throughout New Zealand.

6. *Control of Pear Slug* (*larva of Eriocampoides limacina*).—This pest is bad on pear, quince, plum, cherry, and hawthorn throughout New Zealand and Tasmania, and in parts of Australia. An attempt was made to introduce from England the ichneumon parasites of the genus Perilissus. Consignments were sent to the Cawthron Institute from Rothamsted Experimental Station. Nearly two years elapsed before the insects hatched out. They were then carefully paired in special cages and liberated into an insectary containing plenty of pear slug, which they attacked with vigour. It seemed almost certain at that point that success would be attained. But, alas ! one of the unknown bionomic factors intervened, for the entire succeeding brood proved to be males, and so the race died

out. This extraordinary example of the difficulties attending this kind of research may fittingly be used as an extra argument in favour of giving the strongest encouragement to those engaged in pure entomological research. Until we know for certain the factors governing the production of single sex broods in Hymenoptera, and also far more about parthenogenesis in this order than we do at present, we may not be able to succeed with the introduction of many valuable parasitic insects into Australia and New Zealand.

7. *Control of Sheep-Maggot Flies.*—This immense problem, of the utmost importance to Australia and other sheep-raising countries, need not be dealt with at all fully here, because up to the present no satisfactory method of biological control has been discovered. Much work has been done with several well-known chalcidoid parasites of the blow-fly larvæ and pupæ, but in no case has the percentage of parasitism produced been high enough to warrant the continuance of the work. At the present time, the interesting parasitic hymenopteron *Alysia manducator* is being collected in England by Dr. J. G. Meyers for shipment to Australia, and it will be interesting to watch the progress of the attempt to acclimatise and spread this very active insect in a warmer climate and new conditions of life.

8. *Control of Coco-Nut Moth* (*Levuana irridescens*).—This very serious pest, the original home of which is still unknown, is a small zygænid moth the larva of which feeds along the midrib of the leaflets of the coco-nut palm. In the island of Viti Levu, Fiji, it increased enormously during the past ten or twenty years, until its depredations had so weakened the trees and reduced the yield of copra that the very foundations of the industry were tottering. During the past few years scientific workers have been engaged on the problem of discovering and introducing the natural enemies of species closely allied to *Levuana iridescens* from Malaya. A parasitic tachinid, *Ptychomyia remota*, has been introduced and successfully established with very promising results, and it would appear that this formidable problem is now in process of solution.

(*To be continued.*)

Whither ?—a Footnote.

"*What, then, is Life? Is it . . . a . . . possibly quite unimportant by-product of natural processes, which have some other and more stupendous end in view? . . . Or, throwing humility aside, is it the only reality, . . .?*"—J. H. Jeans, NATURE, Dec. 4, 1926.

RIBBED, breathing flesh thrice often crucified!
Veined vase of Life! lo, whether for bliss or curse
A wondrous thing the wheeling universe,
Engendering thee, lifts shapen from scarred Earth's side!
Reared in primeval war of rock and tide,
Thence hither—by what wayfaring perverse!
Thy fashioning? runs it ended more than theirs,
The stars in flow that sphere from vapours wide?
How camest thou by that strange gift ungiven
To aught else earthly, the old fruit forbidden,
To know thyself, as part to glimpse a whole,
And, that within thee, clasping earth and heaven
For comrades of like faring, to—storm-ridden—
Confront, brow raised, the incognisable goal?

C. S. S.

Obituary.

PROF. A. DE QUERVAIN.

THE death of Prof. A. de Quervain at the comparatively early age of forty-seven years, which occurred at Zurich on Jan. 13, is a serious loss to European meteorology. His fellow-members on the different international commissions to which he belonged will miss a colleague who had endeared himself to them by his earnest enthusiasm and by his lovable disposition.

de Quervain was born on June 15, 1879, in the Canton of Berne. After studying at Neuchâtel and Berne he went to Paris as assistant, from 1898–1902, in the Observatory at Trappes, where the late Teisserenc de Bort was developing the exploration of the upper atmosphere by means of *ballons-sondes*. This led, in 1899, to the discovery of the stratosphere. In 1901, Teisserenc de Bort made arrangements for observations with *ballons-sondes* in Russia. Prof. de Quervain was placed in charge of the work and obtained observations of temperature in the upper air both at St. Petersburg and Moscow up to heights of 10 kilometres. After leaving Trappes, de Quervain went to Strasbourg, where the results of the international investigation of the upper air were collected and published under the direction of Prof. Hergesell. de Quervain acted as secretary to the international commission, and became impressed with the advantages which would accrue if the balloons which were used for carrying the recording instruments could also be observed during their ascent, so as to give information about the upper wind. Physical difficulties in the way of making these observations for an hour or more with an ordinary theodolite had formed a practically insuperable obstacle. de Quervain overcame this difficulty by inventing, in 1905, the theodolite with the reflecting prism, which is now practically universally adopted for observations with pilot balloons: no invention has contributed more than this to our knowledge of upper wind. It was exceptionally fortunate for meteorology that de Quervain came, during these eight years, under the influence of two such pioneers in the investigation of the upper air as Teisserenc de Bort and Hergesell. They were both inspired with the conviction that the exploration must be world-wide, and themselves carried out investigations in different parts of the oceans.

Prof. de Quervain returned from Strasbourg to Zurich, where he continued his investigations of the upper air, publishing in 1908 a thoughtful contribution on cloud studies and some notes on