and Queen's Wharf and the Queen's Bond on payment of the amount of £31,000; £19,000 being the amount asked for the wharf and bond. The Bill became law during the same year, under the title "Wellington Reclaimed Land Act."

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The Chemistry of Bush Sickness, or Iron Starvation, in Ruminants.

By B. C. ASTON, F.I.C., F.N.Z.Inst.

[ABSTRACT.]

IN 1911 the writer published (*Trans. N.Z. Inst.*, vol. 44, p. 288) some preliminary results of his work on bush sickness, a wasting, non-transmissible disease in ruminants, characterized by excessive anaemia, which ultimately proves fatal if the animal be not removed to healthy country. The disease occurs over a large area of country in the thermal district of the North Island. The iron-starvation theory was first published as an hypothesis by the writer in the August, 1912, *Journal of the Department of Agriculture,* p. 124. Since then the work has been continued, the evidence becoming stronger every year, until now it is thought that iron deficiency as a causative agent has been fully proved. (See the series of articles, *Journ. Dept. of Agric.*, April to August, 1924.) The matter is of great economic importance, as not only is the area affected very large (at least a million acres, and probably much more, being affected), but doubts are cast on all pumice lands, the settlement of which is thereby retarded. The soil in the affected area is always derived from an air-borne coarse pumice several feet in depth, resting on rhyolitic country rock. Apparently pumice soils which have been sorted out, compacted, and weathered by water are not bush-sick, since river-terraces and lake-terraces, unless overlain by recent aerial deposits, are free from the disease. Topographical and soil surveys, which are now being carried out, may be expected to throw considerable light on the distribution of bush sickness. The analysis of the blood of sick animals published in 1911 showed a great deficiency of iron, although the grass-ash failed to show any such deficiency. Grass is, however, easily contaminated by soil, and this pumice soil would yield about ten times more iron to the hydrochloric acid than would the grass-ash. Hence, unless

special pains are taken to guard against the entry of this impurity into the samples, unreliable results are obtained. Similarly, pumice soils are entirely abnormal in mechanical composition, the particles consisting of an easily broken solidified froth. This cannot be analysed by the standard methods in use for determining the mechanical composition of ordinary soil. If such methods are used they give unreliable results, the finer fractions tending to become higher in quantity owing to the breaking-down of the particles in the course of preparing the sample for the analysis. The clue afforded by the analysis of blood, suggesting the deficiency of iron, has been followed up in the work undertaken by the Department in the Dominion Laboratory and in the field during the past fourteen years. Areas have been leased and field experiments conducted thereon. Finally, a demonstration farm was purchased at Mamaku, in the heart of the bush-sick country, in an endeavour to learn a practicable method of farming this type of land without periodically changing the stock to healthy country, as is the practice at present. This country is more adapted to cattle than to sheep farming, and, could a practicable remedy be discovered, a great area would be available for dairy-farming.

The chemical part of the work, which has been under the immediate direction of the writer, comprises the analyses of soils, fodder plants, and animal specimens, and these have not shown the presence of any known poison. The absence of poison is, however, indicated by certain facts. Horses may be kept in perfect health for many years upon the same pasture on which ruminants would die in three to nine months, sheep being most and cattle least susceptible. Ruminants, however, when given turnips and hay made from the bush-sick pasture, can be kept healthy while still grazing on the same pasture which as a sole ration would bring on bush sickness. Molasses, bran, and other imported concentrated foodstuffs added in small quantity to the natural ration enable an animal to be kept healthy on the bush-sickness-inducing pasture which, if it contained a poison, would undoubtedly continue to exert its deleterious effects. Again, when an animal at the onset of the sickness has been sent away for a change to healthy country, and after a few months it returns in poor store condition to the pasture upon which it was becoming sick, it fattens or improves greatly in condition. These facts alone, the writer considers, are sufficient to disprove the possibility of poison being present in the natural fodder—cocksfoot-grass and clovers. The author considers that there can be no other explanation of the cause of bush sickness but that which postulates a deficient food-ingredient. It is not to be thought that the organic nutrients are deficient; grasses and clovers grow particularly well on these pumice lands, and provide an ample organic ration. It must therefore be in the mineral or inorganic portion where one must search for the deficient ingredient of the elements necessary to maintain animal life—calcium, phosphorus, potassium, sodium, magnesium, chlorine, iron, and sulphur, named in the relative order in which they occur in the animal's ashes. Iron is the only element about which there can be any doubt as to its presence in sufficient quantity. Phosphorus, although often deficient in the soil, is obviously not low enough to produce nutrition disease in the animal. Phosphorus is stored in the bone of the animal; bush-sick animals show no disease of the bones or other symptoms usually manifested by deficient phosphorus-supply in the diet. Moreover, administration of phosphates to the animal, either medicinally or through the pasture, does not enable them to be kept permanently free from bush sickness. There may be other elements which

are required in very small quantities, such as fluorine and iodine. Nothing is known of the exact need for the former, which must be required only in very small amounts, and the latter has been administered to a sick beast without effecting any improvement. Bush sickness occurs in coastal districts where sulphur is not likely to be wanting. Thus by a process of elimination one naturally arrives at iron as being the deficient element. Of the igneous rocks, the rhyolites, from which the bush-sick soils are derived, are among those rocks which contain least iron. The rhyolitic froth—pumice—which forms the soils, had no doubt been leached before being redistributed by a series of explosions in geological time, long after its formation in the volcano. This redistribution took place, according to Thomas,* not long before the Maori came to New Zealand, which would be probably about a thousand years ago.

The amounts of iron extracted by hydrochloric acid from these pumice soils is of the order of 1 per cent., but the amount extracted in Dyer's 1-per-cent. citric-acid method for "available plant-food" gives about 0·03 to 0·07 per cent. iron, whereas on non-bush-sick pumice soils the amount rises from 0·07 to 0·1 per cent., and on non-pumice soils it may rise to 0·3 per cent. These amounts for iron, compared with the standard amounts required for other constituents—phosphoric acid and potash—in the Dyer method, are high, but the standard for iron may need to be a high one. Another remarkable fact is that when bush-sick pasture is top-dressed with lime the animals become bush-sick sooner than on land which has had no treatment. This may be connected with the well-known fact that chlorosis of plants often occurs on sandy land containing an excess of lime.

It is when one comes to the analyses of fodder plants that the first good evidence of iron deficiency is obtained. Pfeffer (*Physiology of Plants*, p. 428) states that ordinary plants are fully supplied with iron when 0·2 per cent. is present in the ash; but he is no doubt looking at the matter from the plant's point of view, and not from that of the animal which has to subsist on the plant. Analyses of the fodder plants, grasses, and clovers from the bush-sick country show that the iron content of the ash may sink to 0·05 per cent. Although the plant apparently continues to be healthy with this small amount of iron, it may not be sufficient for the animal. The analyses of clovers and grasses of the sick area show that the iron content is very much lower than that of similar plants growing on healthy country. Recent work by Dr. Orr, the Director of the Rowett Institute, Aberdeen, and his associates, has directed attention to the importance of inorganic foods in animal nutrition. An account is given of iron starvation occurring in pigs, when the mother was fed on a fish and vegetable diet containing 1,068 milligrams of food iron per day. It is suggested that the mineral-food requirement of each species of animal may be indicated by the composition of the milk of the species. The faster an animal grows, the more mineral food it requires. A young pig doubles its weight in ten days, but a calf takes forty-seven, a colt sixty, and a human child 180 days. Human milk and mares' milk contain one part, cows' two parts, and pigs' nine parts of iron in equal portions of milk. It is suggested by Kellner that an animal requires two to three times the amount of mineral food that it is able to store up. Sherman lays down the dictum that 12 milligrams of iron per day should be sufficient for an adult human being. Using this data and applying the corrections necessary—*i.e.*, (*a*) for the increased

* A. P. W. Thomas, *Report on the Eruption of Tarawera and Rotomahana, N.Z.*, Wellington, 1888, p. 19.

weight of the species, (*b*) for the increased amount of iron required as shown by the iron content of the milk of the species, (*c*) for the allowance suggested by Kellner for phosphoric acid and lime (two to three times the amount which is present) and assuming that the same holds good for iron, one arrives at the conclusion that if the pasture contains only 0·0025 per cent. of iron, and a cow eats 100 lb. per day, there is good reason to suppose that 1,132 milligrams of iron per day is insufficient for the animal's requirements. A horse, which grows only at one-sixth the rate of a sheep, and the milk of a mare containing only one-ninth of the iron found in sheep's milk, may similarly be shown to be sufficiently supplied with iron from a pasture upon which cows and sheep suffer from iron starvation. Analyses of pasture-plants grown in pots and in the field establish the fact that the iron content of the portion grown in spring and early summer is much lower than that of the portion found in autumn. It is in the spring and early summer that bush sickness is prevalent.

Finally, numerous and long-continued feeding experiments on cattle, and medicinal treatments, have demonstrated conclusively that, although many substances may alleviate or postpone the onset of symptoms of bush sickness, there is only one which will bring an animal back to health when badly affected, the food being unchanged. That substance is a soluble salt of iron, the best of all for the purpose being the double citrate of iron and ammonium, the ferri ammon. cit. of the druggist.

It is to be regretted that the exact iron requirement of ruminants is unknown. The conjectures which are here made as to the requirements are introduced to complete the chain of evidence and to show that iron starvation on green pasture may not be impossible. The main portion of the proof must rest on the evidence supplied by the analysis of the pasture, the soil, and the animal, compared with normal specimens; the medicinal means by which the animal may be restored to health; the manurial means by which the pasture may be rendered capable of growing healthy animals; and, lastly, by the symptoms exhibited by the sick and dead animals to prove that bush sickness is really iron starvation.

There is reason to believe that bush sickness exists in parts of the Dominion other than in those on the pumice lands, but always on a soil of loose sandy nature, or derived from an acidic igneous rock of low iron content. In these cases, owing to the proximity of soil and pasture of higher iron content, and the feeding of supplementary fodder crops in winter, the effects are not likely to be so serious as in those pumice lands where these conditions do not obtain. Further, in at least three widely separated countries outside New Zealand a nutrition disease exactly similar to bush sickness develops, and the writer predicts that it will be found that the cause is in each case the same—viz., iron starvation. These external areas are—(1) In King Island, off the coast of Tasmania, in sandy soil, where the disease is known as "coast disease"; (2) in the Kedong Valley, Nairobi, British East Africa, on a grey volcanic ash, where a wasting disease occurs in cattle; (3) in North Britain, in the Cheviots, and in various parts where a disease in sheep known as "pining," "vinquish," or "daising," occurs on soil derived from porphyritic rock.