The Law of Irreversible Evolution*

Critical Notes upon Dollo's Famous Hypothesis

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Louis Dollo, the great Belgian palaeontologist, first formulated publicly¹ in 1893 his celebrated law of irreversible evolution, one of the most important laws governing organic evolution.² This law has been often discussed and applied, but so far as I know no one has attempted to make an exposition of it based upon the various works of Dollo himself. It is this task which I undertake to perform here, at the same time adding to my exposition of the law in question certain critical remarks upon its value.

The law of irreversible evolution was formulated by Dollo as follows: An organism cannot return, even partially, to an anterior state previously attained in the series of its ancestors.³

The commonly accepted view is that the law thus defined relates solely to parts or to organs which have been reduced or which have disappeared, but this view is inexact. The scope of the law is far more vast, for it also embraces the functional organ.⁴ In order better to understand the wide scope embraced in this law of Dollo it is necessary to make certain distinctions in the concept of organic evolution and to define it more precisely.

As we know, organic evolution may be divided into three classes, progressive, retrogressive and mixed.⁵ If progression predominates in mixed evolution (which is the most wide-spread type in the realm of organic evolution), or, in other words, if the final state attained represents progress in comparison with the initial state, then we call this kind of mixed evolution ascending evolution—pure progressive evolution representing the ultimate form in this sort of evolution. But if retrogression predominates in the mixed evolution, or, in other words, if the final state attained is a throw-back in comparison with the initial state, we call such evolution descending evolution—pure retrogressive evolution evidently representing the ultimate form of this kind of evolution. The best known example of mixed ascending evolution is found in the foot of the horse, which is composed of a single digit and which was evolved from a five-toed foot by the atrophy of the lateral digits and the comparatively greater increase in size of the middle digit; an admirable example of descending mixed evolution, on the other hand, is found in the comparison of the skull of the living *Ceratodus* with the skull of the *Dipterus*, its probable ancestor in the Devonian period.

By keeping in mind the definitions just formulated, on the one hand, and on the other the examples given further on, cited by Dollo in support of his law, we shall be able to separate the cases of ascending evolution from those of descending evolution, a thing which was not done even by Dollo himself. It is evident that if the structure or the parts of an organ be lost through descending evolution, and if it is not possible, as is almost unanimously agreed, to re-establish the lost structure or the lost parts by a new ascending evolution, it nevertheless by no means follows—at any rate *a priori*—that a reversibility of the evolution might not be possible in the contrary case, i. e. when

the structure of an organ has been lost through the ascending evolution of the said organ.

It is necessary, therefore, to replace the single law of Dollo by three different laws, one of which, the first and the most fundamental, shall express the impossibility of the reacquisition of the lost parts, while the second concerns those cases in which the structure of an organ has been lost through ascending evolution, and the third those cases in which the structure has been lost through descending evolution. These three laws may be expressed as follows:

1. The organs and the parts of organs which have been reduced or lost through retrogressive evolution cannot be regained by a new progressive evolution.⁶

2. If the structure of an organ has been lost through ascending evolution (with or without the addition of new parts, and with or without the loss of certain parts), then the lost structure cannot be regained: (a) either by the reacquisition of the lost parts, since such reacquisition is impossible in virtue of the first law; (b) nor by the retrogressive evolution of new parts, since the total disappearance of such parts is impossible; (c) nor by the ascending evolution of these new parts in a new direction.

3. If the structure of an organ has been lost through descending evolution (with or without the loss of certain parts), then the said structure cannot be regained: (a) either by the reacquisition and progressive evolution of the lost parts, such reacquisition being impossible according to the first law; (b) nor by the ascending evolution of the non-reduced parts in a new direction; (c) nor by the ascending evolution of the parts which are entirely new.

We will now explain the different cases falling under these three laws by examples found in the writings of Dollo.

The examples to which the first law applies are very numerous. The birds lost their teeth during the Cretaceous period; no bird of a later period was able to regain these lost parts. The jaw of the mammals consists of a single piece which is homologous to the tooth-bearing part of the reptilian ancestors, and no mammal has been able to regain the other lost parts of the reptilian jaw, etc.

These examples in which the return to the adaptation found in the ancestors would require the reappearance of the lost parts of an organism demonstrate especially well the validity of the first law; as they are also examples of the other two laws we shall expound them in connection with the latter.

The best known example of the first case under the second law is the pseudo-dentition of the *Odontopteryx*, a fossil bird of the Eocene period. Instead of having the true teeth, which had been lost, the *Odontopteryx*, has the edges of the beak and of the lower jaw toothed like the edge of a saw. The most striking example of the second case, under the second law, is the pelvis of the Triceratops. The Dinosaurian ancestors of this animal adapted themselves to living as bipeds and as such they possess a very long and very narrow ischium, and a pubis provided with a postpubis which was likewise very long and narrow.⁷

In its secondary adaptation to life as a quadruped the Triceratops was not able to regain morphologically the triradial pelvis of its remote quadruped ancestors. For it had preserved the traces of the biped phase in the rudimentary postpubis and also in the narrow and curving ischium of its pelvis; i. e. the postpubis, the new part acquired during the biped life, had not succeeded in entirely disappearing and in the same way the new form of its ischium had not been able to disappear.⁸

The most evident example, and likewise the most important, of the third case under the second law is also found in a Dinosaurian closely related to the preceding one, namely, the *Stegosaurus*. The immediate ancestors of this animal were bipeds like those of the Triceratops, and like the latter it readapted itself to the life of a quadruped. But while the triradial pelvis of the remote quadruped ancestors was re-established

physiologically by retrogressive evolution (by means of atrophy) of the postpubis and of the ischium in the Triceratops,⁹ in the *Stegosaurus* these parts have undergone evolution in a new direction. Here the ischium is shortened and flattened and so is the postpubis, which, moreover, lies closely along the lengthwise ventral edge of the ischium. But from the morphological point of view neither have we here a return to the state of the triradial pelvis of the past, for the ischium has preserved some trace of the form acquired in the biped phase and the posterior branch of the pelvis is no longer constituted by the ischium alone but by the ischio-postpubic complex. By developing this new direction the postpubis has, therefore, undergone a change of function.¹⁰

We find an example of the first case under the third law in the evolution of arms in the octopus. The octopus in adapting themselves to the benthonic life have lost one pair of arms (the tentacular arms) of their immediate ancestors, the heteropod decapods. Thus they have become isopods once more (apart from the exceptional case of the Argonaut and the hectocotylization of one of their arms) like their remote ancestors the Belemnotheutides isopods and decapods, without having been able to regain the same number of arms.¹¹

The most important example of the second case of the third law is the foot of the *Dendrolagus*, a tree-living kangaroo. The structure of the foot of the jumping macropods—the predominance of the fourth toe, the syndactylism of the second and the third, the reduction of the fifth, and the total disappearance of the great toe, shows us that their immediate ancestors were arboreal. In the *Dendrolagus*, a macropod which became arboreal once more, the great toe capable of being opposed to the other toe, like the thumb in the hand of man, which was entirely atrophied in its immediate ancestors, the terrestrial kangaroos, was not able to reappear, but the non-reduced parts underwent an ascending evolution in a new direction. While the metatarsals and the phalanges have diminished in length, the phalangines, the phalanges and the claws are elongated and the latter are also curved. Thus the foot of the *Dendrolagus* has not been able to revert to the structure of the foot of its remote tree climbing ancestors which possessed an opposable great toe, a united second and third toe, a predominant fourth toe, and reduced claws.¹²

Finally, we have as an example of the third case, under the third law, the secondary carapaces and plastrons of the *Dermochelys* turtle. The remote ancestors of this turtle were marine turtles, like itself; its reduced primary plastron (a ring composed of four pieces) and its still more reduced primary carapace (represented by the single nuchal plate) bear witness to this. In adapting themselves to shore life the immediate ancestors of the *Dermochelys* regained a carapace and a plastron, but this carapace and this plastron are parts of entirely new superficial dermal origin. In readapting itself to marine life the *Dermochelys* has preserved this athecous plastron and carapace of its immediate ancestors, although both are already considerably reduced.¹³

The importance of the law of irreversible evolution is manifold. In the first place it possesses a phylogenetic application, i. e. it enables us to reconstitute with the very often insufficient paleontological material at our disposal, if not the actual phylogenetic series, at any rate, series representing incontestable stages of evolution. Its ethological application is still more important, for it is often the only means by which we can determine the conditions of existence under

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¹Dollo, The Laws of Evolution; Bulletin of the Belgian Society of Geol., etc.; VII., 1893, pp. 164-6.

²He had already announced this law in 1892 in his lectures upon the evolution of the vertebrate skeleton, at the Solvay Institute, University of Brussels; also in a note in the Bulletin mentioned in note 1.

³I. c. Note 1. Later he phrased the law with even more precision: "An organism never resumes an anterior state precisely, even when placed in conditions of existence precisely identical with those previously traversed. But in view of the indestructibility of the past it always retains some trace of the intermediate stages through which it has passed." In this connection it should be noted that he expressly admits the reversibility of the conditions of existence: "Evolution is irreversible with respect to the structure of organisms, but reversible as regards conditions of existence."

⁴Dollo, Ethological Paleontology, Bull. Soc. Geol., XXIII., 1909, notes, pp. 377-421. Refer especially to remark 2, p. 400.

⁵In my open course on universal evolution at the Sorbonne for the present year, which will be published later, I have defined evolution in general in the following manner: "Evolution is the formation of a thing by means of successive degrees of change." When each successive state in the progress of evolution contains something more than the preceding state the evolution is progressive, and it is regressive when each successive state contains something less than the preceding one. It is mixed when in a complete organism undergoing evolution, one part evolves progressively and another part regresses.

⁶For the first law see Dollo, On the Origin of the Luth Turtle (*Dermochelys Coriacea*), Bull. Roy. Soc. Med. and Nat. Sci. of Brussels, 1901, pp. 1-26; A New Tympanic Opercle of *Platystrophia* (*Mosasaurian Diver*), Bull. Belg. Soc. Geol., XIX., 1905, pp. 125-131; and the reference of note 4.

⁷Dollo, The Dinosaurians Adapted to the Secondary Quadrupedal Life, Bull. Belg. Soc. Geol., XIX., 1905, pp. 441-8.

⁸I. c. note 7, p. 446, 447.

⁹Dollo, The Cephalopods Adapted to the Secondary Necteric Life and to the Tertiary Benthonic Life, Zoolog. Jahrbucher, Suppl. Vol. XV., 1912, pp. 105-140. A still more convincing example would be the secondary stegocephalism of the *Chelonia*. This is distinguished from the primary stegocephalism of the ancestral stegocephalic amphibians by the fact that the postorbital, the supratemporal and the epiotic, when once lost, do not appear again in the cranial vault; Dollo, *Podocnemis Congolensis* and the Evolution of the Fluvial *Chelonia*, Annales du Musée du Congo-Belge, Brussels, 1910, pp. 49-65. But the secondary stegocephalism of the *Chelonia*, although very probable, is not yet established beyond a doubt—see particularly the recent note by G. A. Boulenger, The Position of the *Chelonia* in Classification, *Compt. Rend.*, Vol. 167, 1918, p. 514. See also D. M. S. Watson, *Eumotosaurus Africanus*, Proc. Zool. Soc., London, 1917, p. 10-11 ff.

¹⁰Dollo, Did the Ancestors of the Marsupials Live in Trees? Biological Miscellanea, Paris, 1899, pp. 188-203.

¹¹See first reference of note 6, pp. 9-14.

which fossil organisms lived and the method of their adaptation to such life. But this law sometimes possesses a morphological importance also, since by making use of it we are able to distinguish true homologies from simple analogies. Finally, Dollo demonstrated that it could be made to serve also as a guide in classification, and, therefore, that it also possesses a systematic application.

The most important phylogenetic application of the law was made by Dollo in the difficult question of the phylogeny of the Dipneusts, and his extremely ingenious note upon this question must be regarded as a model of philosophic intelligence in the new paleontology. Before Dollo this question was in a truly chaotic state, one of the most eminent paleontologists having declared the *Dipterus*, the most ancient and the most primitive type, to be the most highly specialized type!¹² Nowhere has the idea of the irreversibility of evolution given such brilliant results as here. Since this idea formulates the law that there is never a complete return to an ancestral structure, it can be employed to determine whether an arrangement is primary or secondary, and consequently, when we have a series possessing a sufficient number of intermediate terms between the first and the last term, also to determine the direction of the evolution.¹³ But we do possess such a series in the paleontological series of the Dipneusts: *Dipterus Valenciennesi*, *Dipterus macropterus*, *Scaumenacia*, *Phaneropleuron*, *Uronemus*, *Ctenodus*, *Ceratodus*, *Protopterus*, *Lepidosiren*.¹⁴ Dollo shows us that the structure of the tail as well as that of the top of the head, the scale formation, the jugular plates, the opercular apparatus, the ganoin and the ossification of the mandible, and finally the sub-orbital band, all bear witness to the fact that progress is made in the direction proceeding from *Dipterus* to *Ceratodus* and not in the opposite direction.¹⁵ It is in the structure of the tail in particular that the idea of irreversibility becomes evident. In a long and learned discussion Dollo proves¹⁶ that the diphycercal tail of the Dipneusts (and of other known ancient and modern fishes) is a secondary one, whose morphological value in the Dipneusts, consisting as it does of the second dorsal fin plus the second anal fin, is not equivalent to the morphological value of the primitive diphycercal tail (the caudal fin). Obviously, therefore, there is no return to the primitive structure in this secondary diphycercia.¹⁷

The most important other cases of phylogeny discussed by Dollo are the phylogeny of the Sirenians, of the Luth turtle and of the Holocephales.

One of the most important cases as regards the ethological application of the law of irreversibility is also found in the note on the phylogeny of the Dipneusts. If we supposed the *Dipterus* to be derived from the *Ceratodus*, since the latter is an adaptation to life in polluted water, then it would be necessary to suppose either that *Dipterus* represents an adaptation to life in the mud (intensified muddy water), or else that it represents a return to life in clear water. The first case being that of the *Lepidosiren* only the second remains to be discussed.¹⁸ But, aside from paleontological reasons and those which are purely ethological,¹⁹ the law of the irreversibility of evolution is exactly opposed to this. For "is the lost ganoin recovered? Does the cephalic shield resolve itself into its ancestral element? Will the suborbital fibrous band with its variable number of bonelets again form a continuous arch? Will the opercular apparatus resume its first dimensions? Will the vanished jugular plates reappear?" Since all these things are reduced in the *Ceratodus*²⁰ it is obvious that the *Dipterus* can only represent a primary adaptation to life in clear water,

i. e. that it is a genuine fish ("the most piscatory form of Dipneusts").²⁰

Another important case of the ethological application is the biped life of the immediate ancestors of the *Stegosaurus* and of the *Triceratops*. For "if the evolution were reversible these two Dinosaurians would have regained the exact quadruped form which they had previously possessed, and we should not have been able to distinguish their secondary from their primary quadruped life."²¹

The other important cases of ethological applications are the secondary adaptations to the necteric life of the Pycnodonts,²² the Trilobites *Deiphon* and *Aegolina*, etc.

Among the cases of morphological application those of the secondary abdominal ventral fins in the Teleostians possess a special importance. As we know, the ventrals of these creatures can be either abdominal, thoracic or jugular. But among the abdominal ventrals there are two classes: Those which have absolutely no connection with the scapular band and those which are connected with the clavicular symphysis by a ligament. As there is no reason for the existence of this ligament *in situ* we are bound to suppose that it is the degenerated remainder of a former direct connection with the scapular band. Conformably to the law of the irreversibility of evolution the ventrals have become abdominal again, but they have retained their former thoracic or jugular connection with the clavicular symphysis.²³ The other important cases of the morphological application are: The remotely anterior choanae shown in the marine Chelonians²⁴ and the longirostria and brevirostria of the Crocodiles.²⁵

Finally, it is necessary to mention also the single case in which Dollo made a systematic application of his law, that of the Ptyctodontes. Previous to Dollo these fossil fishes, known up to that time only by dentary plates, were classified among the Holocephales. In his important notes upon this subject²⁶ Dollo has shown in supporting his reasoning by the law of irreversible evolution, that the Ptyctodontes cannot be considered properly as Holocephales but must be regarded as Arthrodera. Since then this conclusion has been fully confirmed. Although the empirical evidence of the validity of his law has been numerous and varied Dollo has not contented himself with purely empirical demonstration. He has attempted also to give a deductive demonstration. With respect to this he says:

"The irreversibility of evolution is not merely an empirical law, based solely upon observed facts, as many persons have believed, but possesses profound causes which reduce it in the last analysis to a question of probabilities, like other natural laws. Since evolution, in fact, is a summing up of perfectly definite individual variations in a perfectly definite order, then in case it were reversible it would be necessary to admit the intervention of causes exactly the opposite of those which have given rise to the individual variations, the sources of the first transformation, and to their fixation, and this in an order also exactly opposite—but these conditions are too complex to permit us to believe that they ever obtained."²⁷

And in speaking of the impossibility of the descent of the *Dipterus* from the *Ceratodus*²⁸ he says: "And it should be observed that we are not here concerned with an isolated character, but with a whole series of characters, which is a much more serious matter with respect to irreversibility . . . but it is in the operation of elements so manifold that we are particularly able to affirm with certainty that evolution is not reversible."²⁹

Thus according to Dollo the greater the number of elements the greater the probability of the irreversibility of evolution, and it becomes a practical necessity when there is a very considerable number of elements. Having expounded the law of irreversible evolution, the different cases which it explains, its applications, and its logical basis, we will now make certain critical observations concerning these different aspects of the said law.

Let us consider first its logical basis. The deductive demonstration attempted by Dollo is very dubious.

²⁰l. c., p. 101.

²¹First reference of note 9, pp. 108-9.

²²Reference of note 4, pp. 410, 412.

²³Dollo, The Teleostians with Secondary Abdominal Ventrals, *Minutes of the K. K. Zool. and Bot. Soc. in Vienna*, LIX., 1909, pp. 135-140.

²⁴Dollo, On the Evolution of the Marine Chelonians (Bionomic and Phylogenetic Considerations), *Bull. Roy. Acad. Belg., Div. of Sci.*, 1903, pp. 801-850.

²⁵Dollo, New Note on the Reptiles of the Lower Eocene in Belgium and Nearby Regions, *Bull. Belg. Soc. Geol.*, XXI., 1907, pp. 81-5.

²⁶Second reference of note 13.

²⁷Second reference of note 9, pp. 59 ff.; also Dollo, On the Morphology of Ribs, *Sci. Bull. France and Belg.*, Paris, XXIV., 1892, pp. 113-129.

²⁸Reference of note 13.

As for the number of elements operative in evolution, it is not the cells which are concerned, but the organs and the parts of organs (because it is the latter alone which possesses definite arrangements in the germen) and the number of these is in comparison not very considerable even in the most complex organism. But if we take into account the much more considerable number of individuals in which the organs and the parts of organs exhibit individual variations, then the probability of their variations in different directions and consequently also in inverse directions, becomes appreciable. It is only when we affirm that the individual variations are predetermined and comparatively few that this reasoning founded upon pure probability begins to totter. But then the law of irreversible evolution would not be the result of probability based on numbers, but the result of unknown internal causes of organic evolution.

Hence there is no logical necessity in the law of irreversible evolution, and the said law rests upon a purely empirical foundation. Let us now see in how far the three laws of the said evolution are confirmed by experience and in what measure we may expect to find possible exceptions.

As for the first law it seems to present no exceptions in so far as it relates to lost parts or organs. In fact, since the loss of an organ or a part has become definite because of the loss of the corresponding arrangement in the germen, it is almost impossible to suppose that there could be a reappearance of the said arrangement, in view of the difficulty of the production of new configurations in the germen by the influence of external causes, on the one hand, and because of the degree of correlation required by these arrangements, on the other hand.³⁰ When the matter in question is a reduced organ or part then the two cases must be distinguished. If the said reduction has advanced so far that the corresponding configuration in the germen exhibits a tendency towards complete disappearance, then the reduced organ or the reduced part is practically as good as lost. But if their reduction has not proceeded to such an advanced stage then their evolution in the opposite direction would not be impossible.

With regard to the second law, we must distinguish the case of a single part from the case of a complex organ. It is evident that the retrogressive evolution of a single part might re-establish the point of departure of the progressive evolution provided no change of form had taken place during either the retrogressive evolution or the preceding progressive evolution. And it is evident also that the retrogressive evolution of a single part might be followed by a new progressive evolution in case the corresponding arrangement in the germen were not too greatly weakened. But if a change of form has been effected during the first progressive evolution and if the said change of form has been so considerable as to necessitate a corresponding change in the configuration of the germen, then neither the retrogressive evolution following the first progressive evolution can re-establish the point of departure of the latter nor can a new progressive evolution succeed in doing this, since this would require the reversion to a configuration which has disappeared. If, for example, a tooth first increased in size and then diminished without any change of form, then this tooth might so diminish as to resume the dimensions it possessed at the beginning of its increase in size, and a new increase of the same form would not be impossible provided the reduction had not proceeded too far. But if the growth in size had been accompanied by a radical change of form, if, for example, a conical tooth had become compressed laterally, then a return to the conical form would not be possible, either during its diminution in size³¹ nor during a new increase in size.

When a complex organ is concerned Dollo affirms that its reversion to an anterior state by means of retrogressive evolution is not possible because of what he calls "the indestructibility of the past." But if a single reduced part of an organ be made the pretended reason of the irreversibility then it may be affirmed with almost entire certainty that in this case the indestructibility of the past does not exist, since it contradicts the well-established law of the retrogressive evolution required for the production of non-functional

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³⁰Compare with similar reflections of A. Handlirsch, cited by Dollo in The Fishes that Spread Sails, *Zool. Jahrb.*, XXVII., 1909, p. 429.

³¹This impossibility is precisely what has been supposed by W. D. Matthew to have taken place during the evolution of *Felidae*, supposing that the felines are derived from the *Dinictis*, a primitive machaerodontous cat; see his Phylogeny of the *Felidae*, *Bull. Am. Mus. Nat. Hist.*, XXVIII., 1910, p. 290 ff. Scott clearly perceives that this phylogeny contradicts the law of irreversible evolution.

¹²See A. S. Woodward, Catalogue of the Fossil Fishes in the British Museum, part II., 1891, p. 20. But after the publication of Dollo's important memoir, Woodward accepted the latter's conclusion; see his presidential address to the Section on Geology, Nature, Vol. 81, 1909, p. 292, and Dollo, reference of note 4, remark 2, p. 387.

¹³Dollo, On the Phylogeny of the Dipneusts, *Bull. Belg. Soc. Geol.*, IX., 1895, pp. 79-128. In treating the question of the phylogeny of the Holocephales, Dollo (The Ptyctodonts Belong to the Arthrodera, *Bull. Belg. Soc. Geol.*, XXI., 1907, pp. 97-108) says: "The idea of the irreversibility of evolution—which led me to the conclusion that I have just attempted to justify—has once more proved its utility, since without this hypothesis we should be obliged to hold that specialized organisms may become primitive once more and then become specialized anew, either in the same or in a different direction. But this is a process which—at least in our present unwillingness to dispose absolutely of complete paleontological series—would destroy every possibility of arriving at the phylogeny; and this is the supreme object of the science of morphology."

¹⁴Reference of note 13, p. 88.

¹⁵l. c., pp. 86, 87.

¹⁶l. c., pp. 89-97.

¹⁷l. c., p. 96.

¹⁸l. c. p. 99.

¹⁹l. c., p. 100.

An Artificial Fertilizer*

Studies on the Influence of Fluorides on Plants

By A. Gautier and P. Clausmann

The well-known French scientists Armand Gautier and P. Clausmann, who have devoted several years of research to the part played by fluorine in living organisms, have just published in the *Comptes Rendus* of the French Academy of Sciences an account of their recent studies regarding the effect exerted by fluorides upon vegetation. Their previous investigations having established the fact that fluorine exists in all the tissues of both plants and animals, sometimes in very small proportions, but sometimes in abundance, as in the bones, the skin and the enamel of the teeth, they were led to the conclusion that this element is indispensable in the vital economy. They also proved that fluorine always accompanies phosphorus in the living cell, that it varies with this element, whose fixation it seems to occasion, and, finally, that it is eliminated in combination with the phosphorus. Since it is evident that the animal organism derives fluorine from the plant substances employed as food and that the latter obtain it from the fluorides and fluophosphates of the soil in which they grow, it occurred to these investigators to study the conditions favoring the assimilation of this element by plants and the effect upon the latter of a lack of fluorides on the one hand or of a liberal supply on the other.

They, therefore, began a series of experiments along this line in 1913, first making use of large flower pots, having a content of four liters each, all placed outdoors under the same conditions. In 1915 further experiments were made in short rows cultivated under the usual conditions of a market garden. Being dissatisfied with the results of these tests the experiments were repeated in 1916 and 1917 on a larger scale, the plants observed being studied in field culture. The results are stated as follows:

In our experiments in pots we attempted to compare cultures in soil as free as possible from fluorine with those made in the same sort of soil, but artificially supplied with fluorine. To secure a soil containing but little fluorine or containing this in an almost insoluble state, we first selected a very pure glass especially manufactured for these tests and reduced to fragments the size of a pea. Since this medium was found to be still too highly fluorated we made use the following

*Translated from *Comptes Rendus* (Paris).

year (1914) of a charcoal made from birch wood, pulverized and washed with hot acids and then with boiling water. This substance was the medium most nearly exempt from fluorine which we were able to prepare, containing only 1.87 mg. per kilo.

a. *Cultures Upon Crushed Glass to Which Fluorides Have or Have Not Been Added.*—These plant species were cultivated in the comparative manner in three pots of a capacity of four liters each, each being placed upon a saucer. In two of them the glass was placed (3,500 gr. each) mixed with a fertilizer of the following composition: Phosphate and carbonate of lime, nitrate of potash, sulphate of ammonia, carbonate of magnesia, silica and aluminum in colloid form, traces of zinc and of iron, and finally, a little bit of very fertile arable earth whose function was to provide microbial flora. This mixture possessed a permeability to water about equal to that of ordinary arable earth, but contained no fluorine except that of the glass, which was nearly insoluble as the glass had been washed free of its own dust. The desired fluorine was then added to these two pots in the form of a dilute solution of an alkaline fluoride. The third pot was filled with ordinary arable earth for the sake of controlling the experiment.

The first experiments were made with fourteen species of plants, belonging to the most various families, and included rye, barley, oats, buckwheat, peas, vetches, beans, morskave, mustard, flax, dandelions, tobacco, fennel, zinnia, etc. Most of these develop poorly in this vitreous milieu; this was specially the case with the peas, vetches, purslane, flax, dandelion, tobacco, fennel and zinnia. Fairly good results were given only by the oats, beans, mustard and California poppy (*escholtzia*). We concluded, therefore, that the vitreous soil formed chiefly of a sodic salt is not suited in general to vegetation. Furthermore, the glass used, although purified, still contained 123 mg. of fluorine per kilo, and by reason of this some uncertainty as to the correctness of our conclusions was felt. We, therefore, decided in 1914 to replace the glass by purified birch charcoal separated from its finest powder. As a source of fluorine we employed only the fluoride of potassium, 2.45 gr. per kilo of carbon or 0.835 grams per pot, taking care always to pour the drain waters into their

respective pots, which were afterwards watered only with rain water. The charcoal soil was made up as follows: Washed charcoal 1,000 gr. (corresponding fluorine 0.00187 gr.; Al_2O_3 added in the state of colloid aluminum = 120 gr. (fluorine = 0); chalk = 730 gr. (fluorine = 0.002 gr.); humus, 27.3 gr.; very fertile arable earth = 66 gr. (fluorine = 0.007 gr.); $CaHPO_4$ = 24 gr.; KNO_3 = 34 gr.; Al_2SO_4 = 30 Gr.; $NaCl$ 3 gr.; $MgCO_3$, 68 gr.; $MnCl_2$, .8 gr.; $ZnCO_3$, .07 gr.; SiO_2 employed in jelly or colloid forms 17 gr.; $FeSO_4$, 180 gr.; sodium arsenate 1.4 gr. It will be seen that this complete mixture, which was normally permeable to water and was composed of the indispensable biological and mineral fertilizing elements, contained only 11 mg. of fluorine per kilo., or 3.97 mg. per pot. The fluorated pots received 300 mg. of fluorine each, i. e. 77 times as much as the control pot; thus our three pots contain (a) a charcoal soil to which no fluorine has been added, (b) an artificially fluorated charcoal soil, (c) ordinary garden earth.

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Of twelve species cultivated under similar conditions but with the addition or non-addition of fluorides, the influence of the fluorine was favorable to seven (cress, cabbage, California poppy, spinach, viper's bugloss, spurrey, and hemp); exerted no effect upon three (convolvulus, onion and rye); while it produced inferior crops in three (sweet peas, chick peas and centaurry).

While this first examination was reasonably satisfactory, since out of twelve experiments seven were successful, we did not consider it absolutely conclusive even in the favorable cases, because of the very small crops obtained from only ten or twelve seeds and in the conditions involved by cultivation in pots; furthermore, since the source of fluorine was potassium fluoride we feared that the fecundity of the crops might have been influenced by the potassium in spite of the very small proportion of this metal present. For this reason we decided to examine the influence of the other fluorides upon vegetation, at any rate the most useful plants, when cultivated in the open field under ordinary conditions. Experiments on these lines were conducted in 1916 and 1917 and we shall shortly make known their results.

The Law of Irreversible Evolution

(Continued from page 87)

organs and parts. The reversibility of the ascending evolution of a complex organ when this depends upon a reduced part is not impossible, therefore; it may be supposed, for example, that the secondary ventrals of the Teleostians will return in the course of time to the primary state by means of the complete disappearance of the corresponding ligaments.

When we are concerned with a part which is not reduced but which has undergone a change of form during the ascending evolution of an organ, then, strictly speaking, the indestructibility of the past also fails to exist, since the non-reduced part may change its form again through a new progressive evolution, although the primary state of the said part, and consequently the primary state of the organ in question, may not be re-established. Hence it is not the indestructibility of the past which is the reason for the irreversibility of the evolution in this case. Let us take the example of the pelvis of the Triceratops. The postpubis of this pelvis exists in a very rudimentary state and since rudimentary parts tend to disappear, if the Triceratops had lived long enough his postpubis would certainly have disappeared. It is not the form of the curved ischium of the Triceratops, very different in form from the ischium of its remote Tetrapod ancestors, which could have prevented the return of its pelvis to the primary state.

Finally, if there be an ascending evolution of non-reduced parts (as in the case of the pelvis of the Stegosaurus) then it is the change of function which saves these parts from a retrogressive evolution; here again, therefore, the indestructibility of the past fails to exist. And it is evident that the same sort of reasoning applies equally well to the third law of the evolution of a complex organ.

To sum the matter up, the irreversibility of the evolution of a complex organ depends entirely upon the irreversibility of the evolution of the various parts, whether reduced or non-reduced, of which it is com-

posed; and the second and third laws are no exception in this respect, for as we have seen, it is always the germinal basis of the first law upon which it ultimately rests.

As I remarked at the beginning of the present article, the majority of naturalists are familiar only with the first law of Dollo, which is only a part of his general law, although it is, to be sure, the most important and the most certain part.³¹ In spite of possible exceptions, this general law is of extraordinary importance both for the doctrines of biology and for evolutionary doctrines in general, and Dollo will always be considered, like Cuvier before him, as the discoverer of a great law of the organic world.³²

A New Alloy

BECAUSE of the high temperature required for suitably hardening tools of tungsten high-speed steel Sheffield toolmakers have sought a substitute metal.

A new alloy produced by adding cobalt to chromium-carbon steel is reported to be best hardened by a temperature of 1,200° C. For most purposes the hardening required is obtained when the tool is cooled naturally in draft-free air. In a comparative test saws of "cobalt-crom," as the new steel is called, continued cutting for four days, it is stated without regrinding, while saws of tungsten high-speed steel were dulled in two days and those of carbon steel in half a day.—*American Machinist*.

³¹Besides the law of irreversible evolution Dollo formulated two others (reference of note 1, p. 165), that of discontinuous evolution (before de Vries) and that of limited evolution. In his later writings Dollo barely referred to these other laws. With respect to the former, see reference of note 13, p. 120; reference of note 6, p. 9; reference of note 9, pp. 139, 140. With respect to the latter, see reference of note 6, p. 9; reference of note 24, pp. 813, 820; second reference of note 9, p. 131.

³²To the list of the works of Dollo upon evolution may be added the important volume by O. Abel, *Principles of the Paleobiology of the Vertebrates*, 1912 (in German), which contains nearly all of Dollo's examples and many others besides. Dollo's law is discussed therein on pp. 616-18.

Constitution of the Sun's Nucleus and Atmosphere

A PREVIOUS paper by A. Véronnet dealt with masses of homogeneous gas. This extends the investigation to mixtures, ignoring the small difference between coefficients of dilatation and compressibility. Under a pressure of 1,500 atmos. the gases reach a density one-third of their limiting density, giving a sudden point of inflection in the density curve and suggesting a surface of separation between the main body of the sun and its lighter envelope. With his previous value of 1.41 for density and 6,000° C. for temperature he finds a mean atomic weight for the nucleus (supposed diatomic) of about 110, nearly that of silver. Then assuming a mixture of 40% Ag, 30% Ta, and 10% each of Fe, Ca, and Na, in order to reproduce exactly his theoretical atomic weight he investigates the change of density with depth, finding the density doubled at about 2 km. and nearly 99% of its central value at 100 km., corresponding to a depth of 1 km. on the earth; at greater depths than this the density is therefore practically uniform. In the atmosphere it is very different. The density is halved at a height of 2 km. and reduced to only 1% at 30 km. The heaviest vapors (Pt, Au, Hg, etc.) cease to have any effect at 20 km., and the silver group (Ag, Cd, Sn, etc.) towards 30 km.

Thus in passing from a height of 20 km. to a depth of 10 km. in reference to the suggested surface, the density increases 110-fold, or from a gaseous to a liquid value, confirming the definiteness of the separating surface, and making it analogous with that of the earth. Now, our clouds hang lower in winter, when convection is less active. So the author suggests that on the sun, if its temperature were lowered, a similar effect would take place, and if the vapors fell so low as 20 km. the heavy gases would appear, and the sun's light having to traverse a layer eight times as dense would look red and much less bright. So also when its temperature was higher it might have been a white star.—*Science Abstracts*.