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Archaeopteryx Is Not a Forgery

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***Archaeopteryx lithographica* might be regarded as the most important zoological species known, fossil or recent. Its importance lies not in that its transitional nature is unique—there are many such transitional forms at all taxonomic levels—but in the fact that it is an obvious and comprehensible example of organic evolution. There have been recent allegations that the feather impressions on *Archaeopteryx* are a forgery. In this report, proof of authenticity is provided by exactly matching hairline cracks and dendrites on the feathered areas of the opposing slabs, which show the absence of the artificial cement layer into which modern feathers could have been pressed by a forger.**

THE HOLOTYPE OF *ARCHAEOPTERYX lithographica* (*1–4*), the oldest species of fossil bird, was found in the lithographic Solnhofen Limestone near Pappenheim (Bavaria) in 1861. Five other fossil birds, generally attributed to the same species with varying degrees of certainty, have been found in the same geological formation. Two of those were found before the holotype: a partial skeleton in 1855 [described in 1857 (*5*) as a new species of pterosaur *Pterodactylus crassipes* and not recognized as another *Archaeopteryx* until 1970 (*6, 7*)], and an isolated but well-preserved feather found in 1861 (*1, 2, 8*) only a few months before the holotype was discovered. The other specimens were found in 1877 (*9*), 1951 (*10, 11*), and 1956 (*12*), respectively.

The skeleton of the species is essentially reptilian (more specifically dinosaurian) with teeth, a long bony tail, abdominal ribs, and three digits on each hand; but it also shows certain bird characters, notably a furcula (wishbone) representing the fused clavicles, a retroverted pubis, and an allegedly perching foot. These avian characters correlate very well with distinct impressions of feathers which, in their distribution around the forelimbs and tail and in their detailed structure, are exactly like those of modern birds. Some at least of these so-called impressions of feathers are now thought to be casts (*13, 14*); for the sake of simplicity, however, we shall refer to them below as impressions.

The authenticity of *Archaeopteryx* has recently become controversial. A group of investigators including N. C. Wickramasinghe and Sir Fred Hoyle, who are associated with University College, Cardiff), has concluded in published material (*15–18*), in the popular media (*19–21*), and at a formal meeting (*22*) that the feather impressions on the holotype of *Archaeopteryx* [now in the British Museum (Natural History)] are forgeries. This has led them to suspect the genuine nature of the other five Late Jurassic bird specimens presently known, all of which are accepted by most modern workers as belonging to the genus *Archaeopteryx* and usually to the species *lithographica*. More specifically, doubt has been cast on the original isolated feather impression of 1861 and on the impressions on the 1877 specimen (housed in Berlin), and they consider the feather impressions on the other three specimens to be so poor as to be unsatisfactory evidence of plumage. Science editors, photographers, and others have been making their own comments (*23*); some preliminary observations were noted by ourselves (*24*).

It has been speculated (*15*) that the motive for the alleged hoax, the subject of which was found only 2 years after the publication of Darwin's *Origin of Species* in 1859 (*25*), was to produce an impressive piece of "evidence" for the concept of evolution. A recent paper (*18*) seems to suggest that there may also have been a financial

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incentive. We—the present official custodians, preparator, and photographer of the holotype—reject this forgery hypothesis unequivocally. It may seem that we, in refuting the consortium's allegations, are using a sledgehammer to crack a rather trivial nut; yet, if we bear in mind the high esteem in which the general public holds Professor Hoyle, together with its lack of knowledge of the facts concerning *Archaeopteryx*, then it is important that such doubts be finally removed—especially where students of zoology are concerned. More important still, we must put the record straight because of the Creationists, who are interested in any new ideas that, implicitly or explicitly, appear to threaten the concept of organic evolution.

The methods used to reveal the so-called fraud (*15*) consisted of the following: (i) taking comprehensive photographs on color transparency film with a hand-held 35-mm SLR camera and low-angle tangential flash lighting and (ii) enlargement, both by projecting the transparency on to a distant screen and by the making of black-and-white prints. These methods were compared with "the cumbersome technique of scanning the surface visually using a travelling microscope" (*13*), to the detriment of the latter. Nevertheless the photographs shown by Watkins *et al.* (*15–18*) have too much contrast and too soft a focus, and some have been oriented by the editor so that the lighting does not conform to the generally accepted convention. We believe that these newer photographs compare extremely unfavorably with photographs of the same specimen taken by Museum photographers (*26*) who, several decades ago, were already using low-angle oblique lighting with far greater success (*4*).

As to the method, it has been claimed that the feather impressions appear to have been "faked" on to a split slab of Solnhofen Limestone containing a small reptile skeleton, more specifically a dinosaur; the claimants believe that feathers of modern birds were pressed into a thin layer of an artificial cement, which could have been made by mixing comminuted limestone from the same deposit with some binder, and which the hoaxer had spread thinly over the surface of the slabs.

The most impressive piece of "evidence" for the forgery, perpetrated as described above, would be the presence of a layer of artificial cement underlying the feathered areas of the slabs (*18*). One manifestation of this was suggested to be the difference between the surface textures of the limestone in the feathered and unfeathered areas, respectively (*15*). Another manifestation of the alleged cement is the presence of well-detailed feather impressions on the main

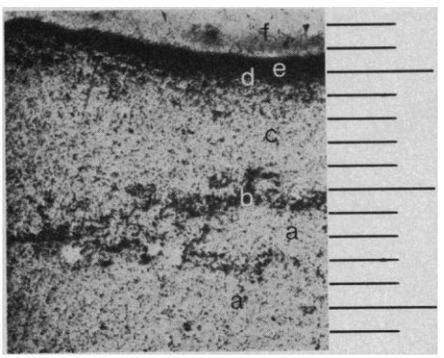

Fig. 1. Polished vertical section through main slab of holotype of *Archaeopteryx lithographica*, B.M.(N.H.) number 37001, exposed surface uppermost. The section is embedded in resin and is viewed by reflected light, using differential interference contrast and a light ground. Each division on the scale is 100 μm; ×32. (a) Inner part of limestone; (b) dark band; (c) outer part of limestone; (d) surface of limestone; (e) birefringence band at surface, due to differential interference contrast; (f) resin.

slab, coupled with their absence on the general surface of the counterslab (*16, 18*); this is thought to indicate that the cement layer on the counterslab had been removed subsequently, either because it was "too complex to match the presumptive feather vanes on the two slabs, or perhaps because material fell off when the counterslab was hammered." This belief is confirmed (for Watkins and co-workers) by a third manifestation—the occurrence on the slabs of smooth, flattened, slightly elevated areas resembling "blobs of chewing gum" (*15*), only a few millimeters in length, not always matched by corresponding depressions on the opposite slab (*16*), and some of them bearing faint but fairly detailed feather impressions. They claim (*16*) that the blobs on the counterslab are fragments of the lost cement layer which the hoaxer, through carelessness, failed to remove entirely.

The limestone was originally a plastic calcareous mud. The "duality of surface structure" (*15*) certainly exists; we believe it is not due to differences in grain size, but to the impression of the animal's cadaver upon parts of the surface. (A similar difference in texture may be seen between a human footprint on a mud-flat and the general surface of the surrounding mud.) In other words, it was the feather impressions that caused the differences in surface texture; not that a difference in surface texture (due to some other cause) permitted the preservation of the impressions in some places and prevented it in others.

Further, there is no discontinuity to be seen between the true limestone and the layer of cement supposed to overlie it—neither on the surface (around the perimeter of the cement) nor in vertical section through the slab. One of us (P.J.W.) has spent hundreds of hours preparing the specimen under a binocular microscope and has never seen the slightest evidence of any cement layer or of petrological differences within the limestone. It is true that the vertical section (Fig. 1) appears to be divided horizontally, certainly when viewed with the unaided eye; there is an outer limestone layer 500 to 850 μm thick, separated from the limestone below by a dark band of an irregular and discontinuous nature (doubtless due to some impurity, organic or inorganic, laid down during sedimentation). The outer layer, however, shows the same granular structure as the layer beneath, and that structure is continuous through the gaps in the dark band that separates the two layers. The complete absence of air bubbles and the presence of traces of calcite crystals confirm that the whole section is original. It should be remembered that the surface has been discolored by dirt, by consolidants applied in the laboratory, and by casting separators; in any case, the outer layer is much too thin to receive any artificial feather impressions.

A third objection relates to the organic bonding material (such as fish glue or gum arabic) that the forger would have had available in the 19th century for mixing cement. By now, after at least 75 years, it would have shown some signs of deterioration such as cracking or shrinking away from the block. We have observed no such indications.

As for the "blobs of chewing gum," those, in our opinion, are natural irregularities in the surface of the limestone as split along the bedding plane. Careful casting of the surfaces of both main slab and counterslab shows that there is always a good fit between the two, except where it has been destroyed by subsequent preparation. In no case is there an elevation on one slab "without any place to go should the main slab and counterslab be closed like the leaves of a book" (*16*).

Our conclusive evidence of the authenticity of the *Archaeopteryx* holotype, however, is provided by what appear to be a number of fine lines on the main slab that run in various directions across the feather impressions in the region of the forelimb (Fig. 2A); some of them extend through the bony elements of the skeleton and on to the tail. They are difficult to spot with the naked eye, but their presence is shown with great clarity by critically lit ultraviolet photography. Associated in a few places with more easily visible linear staining of an orange-brown color, they are presumably hairline cracks and are generally filled with mineral matter. These cracks are also present on the counter-

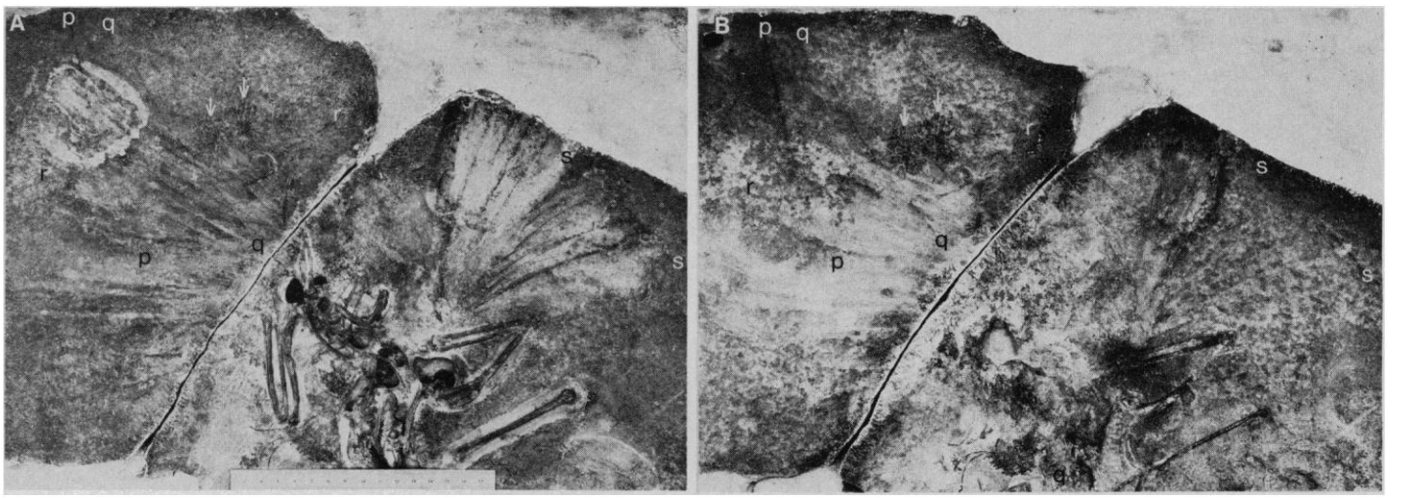

Fig. 2. Photographs in ultraviolet light (wavelength 400 to 300Å) of the London *Archaeopteryx*, B.M.(N.H.) number 37001; ×0.22. The hairline cracks are marked p-p, q-q-q, r-r, s-s. The arrows point to the dendrites overlying the feather impressions that are enlarged in Fig. 3. (A) Part of main slab. The pale area in the top left-hand corner was caused by the taking of a latex peel that removed the surface dirt and discoloration. (B) Corresponding part of counterslab, reversed to facilitate comparison.

slab in precisely the same positions (Fig. 2B); their exact correspondence has been demonstrated by superimposing a negative of the counterslab on to a print of the main slab, the two photographs having been enlarged to exactly the same degree. Such correspondence shows that the block was cracked through vertically before it was split horizontally into two slabs, thus indicating the unquestionable absence of any added cement layer on either surface. Confirmation of that absence is provided by the inorganic dendrites (probably consisting largely of manganese dioxide) that have grown over the feather impressions in places and, like the cracks, match precisely on the two slabs—even in microscopic detail (Fig. 3). We maintain that forgery of exactly corresponding fine cracks or dendrites on to an opposing cement layer would be technically impossible.

Incidentally, if some of the fossilized feathers are not impressions but casts, as suggested by Rietschel's careful taphonomic study (*13, 14*), then they could not have been produced by the "cement layer" method.

Hoyle *et al.*, considering main slab and counterslab, were disturbed by a mismatch in texture and contour (*18*). However, in our experience, the two sides of a freshly split slab often appear (and indeed are) very different and in this instance a great deal of preparation has been carried out over the years.

Another source of controversy has been the regularity of the side vanes of the feather impressions; it has been suggested that the limestone could not split so evenly and that such uniformity must be the product of an attempt at forgery (*16*). However, many rocks have extremely level bedding—especially the Solnhofen Limestone.

Comments have also been made concerning the "double strike phenomenon, indicating that the same feather was printed twice in a slightly displaced position" (*15*). However, we cannot consider this to be evidence of forgery; it would surely be even more difficult to forge than a straightforward "single strike." The double strike had been observed previously in the Berlin specimen (*27*) and in the holotype itself (*28*) (Fig. 4B); the authors concerned disagree as to the best interpretation, and we prefer a more recent explanation (*13*), which claims that two overlapping layers of feathers are represented.

Substantial areas of the present-day feather impressions, around the periphery of both wings and tail and at the base of the tail, were in 1863 still covered in matrix (*3*); it is therefore evident that the total area over which feather impressions are visible has been extended since then, presumably in the Museum laboratory by Museum preparators. The extended area at the end of the left wing on the main slab shows some good feather impressions (Fig. 4A), although the photograph of that area published by Watkins *et al.* (*17*) is too indistinct to show any traces. Their argument is that the counterslab is somewhat swollen in that area; that the main slab, when originally split from the counterslab, must have shown a corresponding depression; and that the 1863 drawing shows no such depression (so that, at the time, it would have been impossible to bring the two slabs closely together). These alleged facts have been explained (*22*) by supposing that, before the drawing was made, feather impressions were somehow forged within the depression and were then covered with an artificial limestone to level the concavity; the purpose of this was to enable the later, overt removal of that "limestone" in order to "discover" the faked feather impressions beneath and thus confirm their apparent authenticity.

We, on the other hand, dispose of the alleged facts more simply by denying them. In particular, we assert that the swelling on the counterslab is only very slight; while it is true that the main slab must have shown a corresponding shallow depression in the area concerned, it must still have been like that at the time of Owen's illustration (*3*) (which really tells us nothing about the contours of the surface). Subsequent work by the preparators revealed genuine feather impressions lying deeper within the rock.

The only other possible method of forging the feather impressions would be somehow to carve them, either into cement or into the actual Solnhofen Limestone. We have therefore prepared "peels" of the feather impressions on the main slab (by means of rubber latex or silicone rubber), coated them with aluminium and subjected them to scanning electron microscopy (Fig. 4, A and B). They show a degree of minute detail that we believe would be impossible to carve, even today, and a total absence of any chisel marks.

We reject also the proposition (*18*) that the so-called feather impressions on the three more recently recognized specimens are too poor to be accepted as such. It is true that none of the impressions approaches those on the London or Berlin specimens in its state of preservation; it is also true that Ostrom wrote (*7*) of those on the Teyler specimen [collected 1855, recognized (*6*)

1970] "were it not for the exceptional preservation of these structures [the feather impressions] in both the Berlin and London specimens, they would not be recognizable in the Teyler specimen." Nevertheless the Eichstätt specimen (found in 1951, recognized 1973) is much better than the Teyler in this respect, while the Maxberg (found 1956) is better still; the impressions on the Maxberg specimen have the structure of feathers, just as in modern birds, and a similar distribution on the wing. We discount the possibility of forgery of all the specimens because the Maxberg specimen shows that, in places, the feather impressions pass under the bony elements, and in other places they are overlain by dendrites.

There is nothing inherently improbable in the presence of feather impressions in the Solnhofen Limestone, despite its early (Kimmeridgian) date. Well-preserved earliest Cretaceous feathers have been reported from Lérida, Spain (*29*), and from Victoria, Australia (*30*). The bony remains of birds, although very rare in the Lower Cretaceous, are relatively abundant in the Upper Cretaceous. If birds existed in earliest Cretaceous times, why not very late in the Jurassic?

In any case, the Solnhofen Limestone is noted for its extremely fine texture (essential for lithography) and for its excellent preservation of the most delicate anatomical structures, paralleled nowhere else in the world. Thus it can display the medusae of jellyfish, the fine hairlike setae of crustaceans, and the wing membranes of pterosaurs.

Watkins *et al.* (*15*) have expressed a belief that the series of retrices forming the tail of *Archaeopteryx* are just one "large and conspicuous tail feather that adorns the creature with ceremonial splendour," the caudal vertebrae representing the central axis of that feather (despite the obviously segmented nature of the tail). Indeed, the individual feathers are attached to the sides of those vertebrae by ligaments (*31*).

If Watkins and co-workers believe that the feather impressions at the end of the wing (*17*) were forged in the British Museum (*22*), then it is a necessary corollary of that belief that Owen, superintendent of the Natural History Departments of the British Museum, was a party to the extension of the hoax; Owen, in their eyes, was responsible for forging "evidence" in support of Darwin. Bearing in mind Owen's well-known hostility toward Darwin and his ideas, we found that suggestion impossible to accept (*22*). Equally unacceptable is the idea (*18, 22*) that Owen "laid a trap" to tempt Darwin and Huxley into making fools of themselves. Not only was it Owen who recommended that the Trustees of the British Museum buy the *Archaeopteryx* (*32*), but also he himself published a detailed description of the fossil (*3, 33*); which means that he, too, would have knowingly been making a fool of himself.

We believe that Owen, despite his animosity toward Darwin and Darwin's ideas on organic evolution, and despite the fact that *Archaeopteryx* appeared to lend support to those ideas, nevertheless recommended the purchase of the fossil out of a spirit of genuine scientific inquiry. We hope that this thorough exposition of the facts will demolish, once and for all, any doubts as to the authenticity of *Archaeopteryx*.

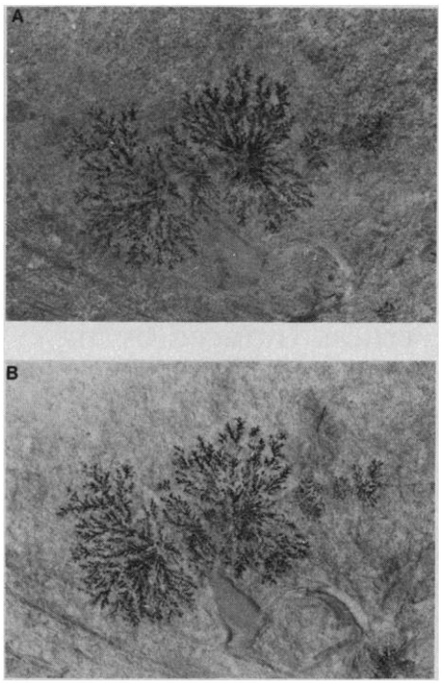

Fig. 3. Enlarged photographs of the London *Archaeopteryx*, B.M.(N.H.) number 37001, showing dendrites overlying feather impressions; ×0.68. For location, see Fig. 2. (A) Part of main slab. (B) Corresponding part of counterslab, reversed to facilitate comparison.

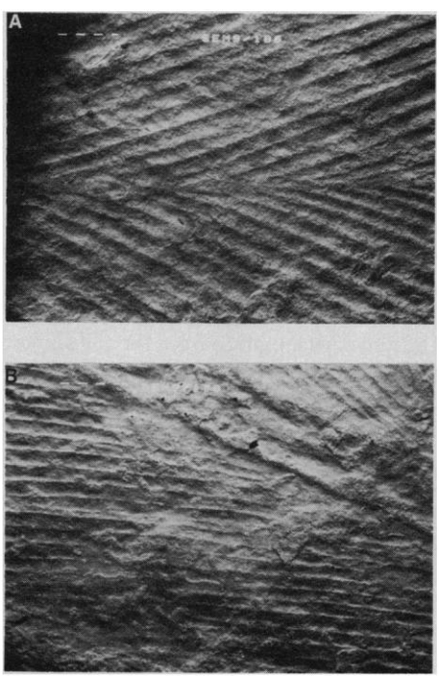

Fig. 4. Scanning electron micrographs of feather impressions on main slab of London *Archaeopteryx*, B.M.(N.H.) number 37001. (Made from latex peels.) (A) On distal part of left wing; ×10. (B) On tail, with "doublestrike" phenomenon; ×7.4. The so-called "doublestrike" is in fact produced by two separate feathers, each showing its rachis.

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Reduction in Summer Soil Wetness Induced by an Increase in Atmospheric Carbon Dioxide

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The geographical distribution of the change in soil wetness in response to an increase in atmospheric carbon dioxide was investigated by using a mathematical model of climate. Responding to the increase in carbon dioxide, soil moisture in the model would be reduced in summer over extensive regions of the middle and high latitudes, such as the North American Great Plains, western Europe, northern Canada, and Siberia. These results were obtained from the model with predicted cloud cover and are qualitatively similar to the results from several numerical experiments conducted earlier with prescribed cloud cover.

IN ASSESSMENTS OF THE POSSIBLE change in climate due to the increasing CO_2 in the atmosphere, major emphasis has been placed on estimating the change in atmospheric temperature. However, for agricultural planning, the change in soil wetness may be just as important. In the study reported here, which is a continuation of earlier studies (*1, 2*), CO_2-induced changes in soil wetness were investigated by means of a mathematical model of climate in which cloud amount is a predicted variable. Because of the large temporal variability of the model hydrology, it has been difficult to distinguish the CO_2-induced change from the natural variability of soil wetness. Therefore, the earlier reports discussed mainly the zonal mean rather than the geographical distribution of soil wetness. To overcome this difficulty, it is necessary to obtain soil wetness of the model averaged over a very long period. The present study represents an attempt to extract the geographical distribution of soil wetness by substantially extending the averaging period.

The mathematical model of climate used for this research is an atmospheric general circulation model coupled with a static mixed-layer ocean model (*3*). The model has a global computational domain, realistic geography, and seasonally varying insolation.

Precipitation is computed whenever supersaturation is indicated by the prognostic equation for water vapor (*4*). It is identified as snowfall when the air temperature near the surface falls below freezing; otherwise it is identified as rain. The moist convective processes are parameterized by a moist convective adjustment scheme (*4*). Cloud cover is predicted whenever the relative humidity exceeds a certain critical value, which is 99 percent in this case. The distribution of cloud cover thus determined is used for the computation of solar and terrestrial radiation (*5*).

A change in snow depth is computed as a net contribution from snowfall, sublimation, and snowmelt that is determined from the requirement of surface heat balance (*6*). The budget of soil moisture is computed by the so-called bucket method (*6*). For simplicity it is assumed that soil can hold 15 cm of liquid water (*7*). When soil is not saturated with water, the change in soil moisture is predicted as a net contribution of rainfall, evaporation, and snowmelt. If the bucket is full, the excess water is regarded as runoff. The rate of evaporation from the soil surface is determined as a function of the water content of the "bucket" and potential evaporation (*8*).

The mixed-layer model of the ocean is idealized as a 50-m-thick, vertically isothermal layer of water with predicted sea ice (*3*). The effects of horizontal heat transport by ocean currents and heat exchange between the mixed layer and the deeper layer of the ocean are neglected.

Two separate experiments were performed: one with the normal atmospheric concentration of CO_2 (300 ppm) and the other with twice the normal value (600 ppm). By comparing the results from the two experiments, the CO_2-induced change in hydrology could be determined. In each experiment a numerical 40-year integration of the model was conducted starting from an isothermal initial condition. Toward the end of this period, the temporal variation of the global mean sea-surface temperature of the model no longer had a systematic trend, indicating that the model attained an equilibrium climate. To distinguish the CO_2-induced change from the natural variability of the model hydrology, the results were averaged over a sufficiently long period, the last 10 years of the 40-year integration. It is encouraging that, in the experiment with the normal CO_2 concentration, the model successfully reproduced the broad scale features in the geographical distributions of precipitation and annual mean runoff.

The geographical distribution of the CO_2-induced change in soil moisture during June to August is illustrated in Fig. 1A. In summer the soil becomes drier over the mid-continental region of North America, western Europe, and Siberia in response to the doubling of atmospheric CO_2.

The reduction in soil moisture over North America, western Europe, and Siberia is statistically significant at the 10 percent level (Fig. 1B) (*9*). In other words, the probability of falsely rejecting the null hypothesis of no change in soil moisture is 10 percent or less in these regions.

To demonstrate the practical implication of the CO_2-induced summer dryness identified above, the change in soil moisture was expressed as a percentage of the soil moisture from the normal CO_2 experiment (Fig. 1C). This result suggests that the CO_2-induced reduction in soil moisture over the mid-continental regions of North America, Siberia, and western Europe amounts to a substantial fraction of the soil moisture present in the standard CO_2 case.

In general, the soil moisture over the model continents in middle and high latitudes is reduced from the peak level in spring to the summer minimum. In high latitudes, this spring-to-summer reduction in moisture is caused by intense evaporation in late spring, when the continental surface absorbs a large amount of solar energy because of strong insolation and the disap-

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