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THE GREAT BATHYLITH OF CENTRAL MONGOLIA¹

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INTRODUCTION

This paper is in the nature of an announcement rather than a discussion. It does not attempt a review of the literature on this subject. Pumpelly, von Richthofen, Loczy, Obruchev and others have noted granite in the Gobi or in adjacent regions. At some other time, an attempt will be made to summarize the geological observations of those who preceded us; and then, we are confident, it will be found that many additional occurrences, some of them far beyond the limits of our own territory, should be regarded as belonging to the same great geologic unit that is emphasized here.

The Third Asiatic Expedition, in the early stages of its traverse across Mongolia, repeatedly noted occurrences of granite. Some are small intrusives, whereas others cover extensive areas of undetermined boundaries. They are associated with so great a variety of other rock formations of widely different ages, that at first there was little to suggest their possible unity. Because of the fact also that the granites themselves show considerable variety of minor character, it was assumed that they were essentially independent intrusion phenomena that might have as great age differences as the hosts with which they are associated.

As the traverse was extended northward from Kalgan, however, a certain similarity of rock type and of field relation was noted, suggestive of a possible common origin. This became all the more impressive in the north and west, where, in many places, the rock floor for tens of miles together is made up wholly of granite.

It is the purpose of this paper to indicate some of the evidence bearing on the structural and genetic relations of these granites, and to support, in more definite terms than has hitherto been done in the publications of the Expedition, the conclusion that they represent a great granite bathylith.

¹Publications of the Asiatic Expeditions of The American Museum of Natural History. Contribution No. 24.

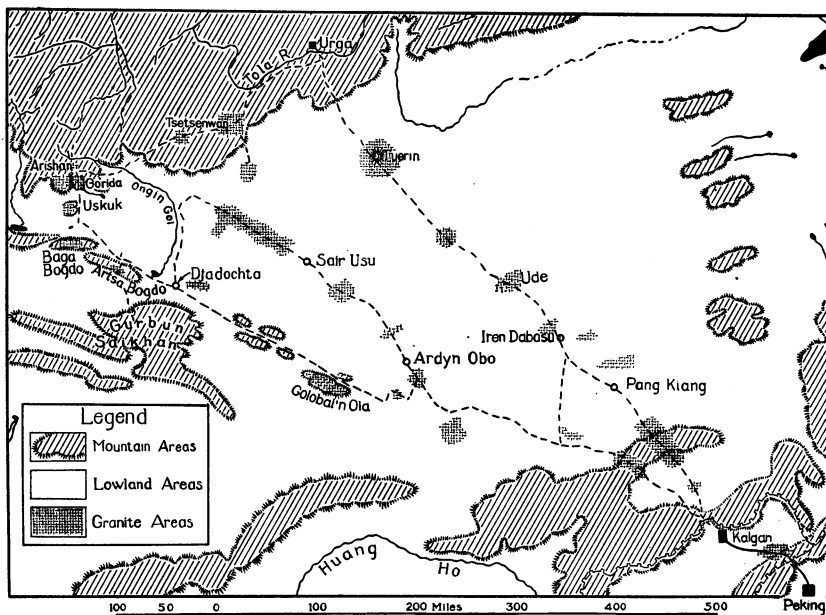


Fig. 1. Location map of the central portion of Mongolia.

This map covers a total area of about 475,600 square miles, showing the principal visited localities where granites of the type believed to belong to the Great Bathylith are extensively exposed. There are doubtless many other exposures lying beyond the reach of the traverse of the Expedition. These already mapped, however, serve the present purpose. A lateral extent of more than 720 miles is indicated, and the total area is probably much greater than the map itself.

SPECIAL LOCALITIES

Many localities exhibit granite outcrops, but particularly prominent and suggestive are those of the granite hills along the Urga trail from 100 to 150 miles out from Kalgan, the vicinity of Ude, 230 miles out, and another stretch of ten miles beginning at 430 miles out. At Mount Tuerin, 500 miles out from Kalgan, granites of several varieties form the floor for 35 miles, the mountain itself being only an erosion remnant wholly composed of granite of a single type. Along the south side of the Tola River on the way from Urga southwestward to Tsetsenwan, intrusive granites in the form of great dikes and bosses become more and more abundant and stand out as prominent elements in the topography. Here the contrast between the erratic igneous bodies and the simple uniform features developed by erosion of the regularly folded graywacke series is very striking indeed. The interrelations of the intrusive bodies and the graywackes, as well as the effects produced, are remarkably well displayed.

The Tsetsenwan district itself exhibits some of the most illuminating relations, for at this place, about 150 miles west of Urga, erosion has cut down through the graywacke roof, not only exposing the massive granite beneath, but also furnishing illustration of the phenomena that might be expected near a great igneous contact. There for a hundred miles, 100 to 200 miles southwest of Urga, the granite either forms the surface or lies so close below that it has broken through in numerous places and has affected the overlying rock in the characteristic manner of contact metamorphism. The same granites outcrop again at the Ongin Gol, thirty miles farther west, and at Arishan, the holy mountain of Sain Noin, thirty

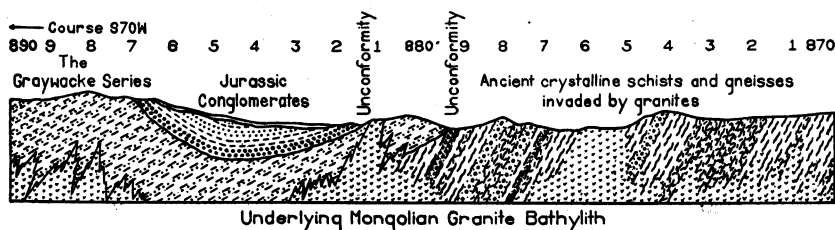


Fig. 2. Geologic cross section of 20 miles between Tsetsenwan and the Ongin Gol.

The underlying granites are repeatedly encountered, and where critical structural relations between the granite bathylith and the ancient gneisses and schists can be seen. Here ancient metamorphic series, separated by conglomerates, are invaded by the granite in a complex way, following the structural weaknesses of the older rock and giving rise to more intimate mixture than is noted where graywacke forms the roof. The contact line is, therefore, more sharply defined with the graywacke than with the older metamorphics. The section includes a small synclinal remnant of the much younger Jurassic conglomerates.

miles farther in the same direction. At Gorida on the Uliassutai trail, midway between Sair Usu and Uliassutai, and at Baga Bogdo, of the Altai system, even the mountains are of granite which has been lifted into prominence by faulting in later time. These are a thousand miles distant from the first occurrences. At many other places between Baga Bogdo and Kalgan there are equally good examples, such as that on the Uliassutai trail, west of Sair Usu, and the mountain area Golobai'n Ola, as well as the large area of granite along the same trail, 400 miles southeast of Sair Usu, within a hundred miles of Kalgan.

Some of these are places where granites have been developed in great prominence, and where their relations to the older and the younger rocks are clearly shown. The structural relations of other long stretches, as well as the connection of one outcrop with another, must of course be inferred. Such of these relations as can be determined make it abundantly evident that most of the granites of Mongolia must be intimately related to one another; and the most satisfactory explanation for them is that

they represent one great underlying granitic mass of enormous dimensions, exposed in patches over the entire area touched by the travels of the Expedition, wherever erosion has stripped off the formations that constituted its roof.

Evidence has accumulated also to show that such mineralogic and textural variety as the granites themselves exhibit probably originated in the processes of differentiation within the magma, and in the process of absorption or syntexis belonging to the normal life history of this ancient magma.

CHARACTERISTIC FEATURES

FACIES OF THE ROCK.—Typically, the granites of Mongolia are light pink or somewhat reddish in color, and are comparatively coarse-grained. In both color and texture, however, they vary greatly. Orthoclase feldspars of light tints are dominant. Quartz is abundant, but even this mineral varies considerably. The dark constituents vary greatly in amount and range from dominant biotite to dominant hornblende, biotite being much the more common. Thus there is a good deal of mineral variation in different localities or individual instances, but the surprising thing after all is the similarity that one finds in them, even in widely separated localities.

Although the common structure is massive and comparatively coarse-grained, there are varieties of strongly porphyritic habit, occasionally an obscure gneissoid arrangement of constituents, and varieties also that range from fine to extremely coarse grain. The larger areas exhibit the most massive habit and the most uniform quality. In many places, these granites are slightly miarolitic and show some pegmatitic tendency, but this is not a striking feature. In the Mount Tuerin area, a hornblende granite, judged to be a facies of the same rock, develops black stains which we believe indicate a small manganese content.

All of these varieties we judge to be understandable as facies of the same magmatic type.

FORMS.—By far the larger number of individual examples appear in the form of dikes, irregular intrusions or lit-par-lit injections. Besides these, masses of very great extent are found, which are best understood as bosses or cupola-like upward extensions of the bathylithic mass, which have been truncated by erosion. Some of the larger areas are twenty miles or more across, with only minor remnants of the former roof to break the monotony. More rarely, one finds very much more intimate relation between the granite and the older country rocks. The granitic

material forms fine injection-bands, and sometimes it is even more intimately mixed, as though it had literally soaked the formation until the whole has become a veritable complex of original rock and introduced granite. All gradations are found, from extensive masses many miles across, that must be part of the major bathylith itself, to dikes of all sizes, and to the most delicate, penetrating stringers and impregnations that seem to die out as they penetrate and mingle with the enclosing host rock.

In other places, especially where the granite cuts the younger formations, there is a sharper contact, though still a very complex one. For instance, at the holy mountain Arishan, the edges of the graywacke are abruptly truncated by the granite. Angular masses of granite rise into the graywacke and send upward long dikes, some of which, branching, completely enclose blocks of graywacke. Pendants of the graywacke extend down into the granite, and xenoliths lie isolated near the contact. These relations suggest that the invading magma reached its present position partly, at least, by stoping.

Thus the mode of emplacement of this great body has probably varied from place to place, involving at least three methods of attack upon the roof:

1. By injection, soaking and even solution and replacement, involving metamorphism of the strata so invaded.
2. By magmatic stoping of xenolithic blocks whose place the magma takes.
3. By mechanical pushing and displacement of overlying rocks.

The three methods are not mutually exclusive, except that simple stoping does not include much of the more complex and intimate mode of attack named as method 1. The third method, that of mechanical displacement, involves the question of the extent to which a large uprising mass of magma may deform rocks and actuate orogenic movements. It is probable that the bathylith caused more or less movement, and, on a relatively small scale, we can see that this has been the case. It is difficult, however, to evaluate the part in deformation actually played as a whole by the bathylith.

Although the common representative is a biotite granite, the fact that there is no distinguishable difference of meaning or structural relation in the hornblende granites or in any of the other varieties makes it look reasonable that they are all simply facies of the same magma, due to a moderate amount of differentiation. There are, however, other masses of exactly the same relations whose compositions depart much more

from the average. Included in these are occasional syenites and diorites, and, rarely, still more basic types. If one includes the "serpent-form" dikes to be described in a later paragraph, and other small masses associated with the granite as host, which are most reasonably explained as closing-stage representatives of internal solidification, the range is still greater. Thus even dolerites and gabbros, found at a few places, may be included among the differentiates of the bathylithic magma.

STRATIGRAPHIC RELATIONS.—These granites cut a great variety of rock formations. No member of the ancient crystalline, metamorphic floor has wholly escaped either actual intrusion or some of the contact effects of this invading magmatic mass. It is clearly younger than any of the pre-Cambrian formations, because it cuts even the great graywacke series of the Tola River region, which has been referred to in previous communications as the Khangai series of graywackes and slates and is regarded as probably the equivalent of the Nan K'ou series of China, the latest of the pre-Cambrian formations.¹ Wherever the relations are clear, it is evident that the folded Khangai graywacke series and the whole confused complex of still earlier series together constitute the roof beneath which this magma solidified.

Subsequent erosion has exposed remnants of this roof that must have extended downward into the magma itself like great pendant projections. Thus, one frequently crosses such surrounded bodies of older rock from granite on one side to granite again on the other, and, because of the insignificant soil cover, one can observe in as much detail as could be desired every transitional and transforming step with all the field relations and effects characteristic of such a history. Some of these roof pendants are most impressive field exhibits, those seen in the Tsetsenwan district being on a particularly large scale. At occasional points, the intimate relations of granite and older rock can be seen in still greater detail, attended by typical contact phenomena.

It is clear, therefore, that the granites cut through formations up to and including the Khangai graywackes. But, because of the scarcity of rocks of determined Paleozoic age, it is much less certain what the relations of the bathylith to the Permo-Carboniferous series of sediments are. No direct associations of bathylithic granite and these upper Paleozoic strata have been observed thus far.

Erosion has uncovered also the relation between the granites and the still younger strata in very many places. At Tsetsenwan the lower

¹von Richthofen, Ferdinand. 1887. "China," II, p. 306.

Willis, Bailey, Blackwelder, Eliot, and Sargent, R. H. 1907. "Research in China," Part I, p. 123, Carnegie Institution of Washington, Publication 54.

Jurassic conglomerates have this relation, and it is clear that the granites had been exposed by deep erosion before that period. (Fig. 3.) In many places, also, Cretaceous and Tertiary strata lie on a granite floor. This fact indicates that, at the time of general post-Jurassic peneplanation and before the development of the later basin sediments, the granites of Mongolia were exposed over immensely larger areas than now.

CONTACT AND MINERALIZATION EFFECTS.—At most places, contact phenomena are not very marked; but typical effects are observed at many places, the sum of which gives the usual list of transformations due to the influence of such a unit. In the Tsetsenwan region, for example,

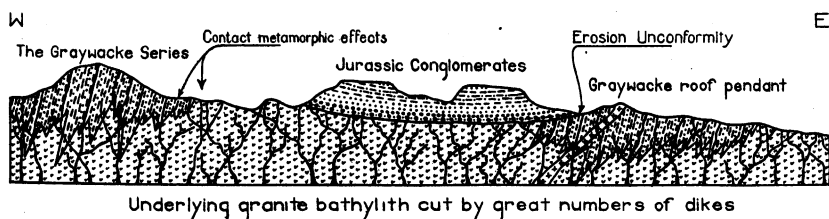


Fig. 3. Diagrammatic cross section of a critical structural relation at Tsetsenwan.

This section lies about 200 miles west of Urga, where erosion had exposed the granite bathylith and carried away most of its roof of graywacke before the Jurassic sediments were laid down. A synclinal remnant of Jurassic conglomerate is preserved here, although several thousand feet of these strata are to be found only a few miles away. Two great denudation epochs, therefore, are represented by these profile lines, and the section illustrates well one of the important unconformities of the region. This particular area exhibits a very fine development of the serpent-form dikes, which cut both the granite and the roof in great numbers, but which are most prominent in the granite areas.

the graywacke-slate series is very heavily tourmalinized, and much epidote is developed. Sometimes there is excessive induration and silicification, as well as silication of the adjacent or overlying rock. Doubtless, also, some of the variations in crystallinity of the overlying metamorphic rocks are due to the greater or smaller influence of the underlying bathylith. For example, the graywacke series, which normally exhibits abundant evidence of its clastic character and is not markedly crystalline, becomes in some places quite strongly schistose with well developed metaphenocrysts. In certain places, it was possible to demonstrate that this metamorphism was due to the presence of the granite. In others, where no granite was visible, its presence close below has been inferred. The only satisfactory working hypothesis is that all excessive metamorphic effects were due to the influence of the granite bathylith.

Thus, in crossing certain country, there are surprising changes in the quality or condition of formations that are elsewhere uniform and simple. Such changes become intelligible in the light of such relations as

are here implied; but they seem anomalous, until one has discovered that, immediately beneath, lies the granite bathylith, and that the effects produced are such as are reasonably to be expected from its influence, even though the granite itself does not reach the present surface.

These metamorphic areas of obscure relation have been checked up repeatedly and compared with the effects produced where the relations are perfectly plain, and there is, in our opinion, no doubt whatever of the major facts. We consider the underlying granite, therefore, to be the dominant cause of all the more pronounced contact metamorphism.

The striking thing, of course, is that metallic mineralization is absent. In the whole of central Mongolia, from the Kalgan border to the Tola River on the north and from the meridian of Baga Bogdo on the west to the Kalgan-Urga trail, surprisingly few traces of metallic minerals have been seen. Even at points where contact phenomena are developed on a magnificent scale, as at Tsetsenwan and at Sain Noin, no important metallic mineralization was noted. Quartz veins, on the other hand, are common, and in a few places such products are developed in great abundance; but none of the veins thus far inspected has noticeable metallic content. In spite of the observed poverty in metallic mineralization, it may well be that elsewhere, particularly on the margins of the bathylith, beyond the reach of our traverse, more favorable conditions for its occurrence exist.

THE SERPENT-FORM DIKES.—One of the most striking features of certain areas is the great number of dikes that cut the granite. They occur literally in thousands and take prevailingly most erratic serpent-like courses. At places such as Tsetsenwan, where, from any good vantage point, it is possible to look out and down upon a large stretch of such country, the whole landscape looks as if it were a tangle of serpent-like forms. In composition, they almost exhaust the range of porphyries. They vary from quartz porphyry and trachyte porphyry at the acid extreme to comparatively basic types,—at least to andesite porphyry and even, though more rarely, to a basaltic type. In size are they equally variable, some of the larger intrusions reaching such dimensions as to form prominent ridges; and they cut each other in a most confusing way. The tangle of tortuous forms is, however, the most impressive feature. Similar structural relations were found at the holy mountain of Sain Noin, but the country there does not lend itself so well to surface display. These dikes stand up under weathering better than does the granite host, and this accentuates the peculiar physiographic effect referred to in the term serpent-form dikes.

What the genetic relation of these dikes is to the granite bathylith is a matter much more difficult to determine, but they have not been noted in such profusion in any place, except in the districts where, judging by the abundance of roof pendants and xenoliths, the present surface is very near the roof contact. They are believed to have originated as an end-product of the deeper interior cooling of the magma mass itself, and thus they actually represent facies of the magmatic differentiation of the bathylithic magma.

OTHER INTRUSIVES.—There are older granites, such as those that form an integral part of the ancient gneisses, which we have tentatively called Archæozoic and have correlated with the T'ai Shan complex in China.¹ Possibly some granites, younger than the T'ai Shan, are yet older than the great bathylith. Such granites are found injecting schists which we believe to be correlated with the Wu T'ai Shan series as described by Willis and Blackwelder for China.²

A few andesite dikes were found cutting the marine limestones of Permian age. Intrusions also of granite porphyry, syenite porphyry and porphyrites of various kinds have invaded the Jurassic conglomerates, sandstones and shales, and there are abundant surface flows with ash and tuff beds associated with these strata in some localities. Some of these porphyry masses are large, and, in many places, the different porphyry units cut each other in a most confusing way, giving a veritable complex of intrusives that completely dominates the geologic structure. The flows include many rhyolitic, fewer trachytic and some andesitic lavas.

After the late Jurassic or post-Jurassic revolution, basaltic lavas and dikes are found in the Lower Cretaceous (Comanchean) formation of Oshih (Ashile), again in the early Eocene basin of Gashato, and in the Oligocene of Hsanda Gol. Similar lavas and volcanic plugs are associated with the sedimentary strata of Wan Chuan Pass above Kalgan, on the eroded edge of the plateau. Most of these flows are basalts, although trachytes and rhyolites also are met with.

How many of these other intrusives, some much older and some much younger, have had a genetic dependence on the underlying granite may be impossible to determine; but it is reasonable to believe that both some of the antecedent and some of the subsequent igneous outbreaks were connected with active stages of the life history of the Great Mongolian Bathylith.

¹Willis, Bailey, Blackwelder, Eliot, and Sargent, R. H. 1907. "Research in China," Part I, p. 19, Carnegie Institution of Washington, Publication 54.

²*Op. cit.*, p. 109.

LOWER PORTION OF THE GENERALIZED GEOLOGIC COLUMN FOR CENTRAL MONGOLIA

COVERING THE STRUCTURAL UNITS OF THE BASIN FLOOR

NOT HITHERTO SUBDIVIDED	GREAT UNCONFORMITY					
	ALL ROCKS BELOW THIS LINE ARE FOLDED					
	MESOZOIC					
	EARLY MESOZOIC	TSETSENWAN SERIES	JURASSIC	A GREAT SERIES OF CONGLOMERATES, SAND-STONES, AND SHALES, WITH ASSOCIATED LAVA FLOWS, TUFFS AND ASHES; CARRYING OBSCURE PLANT REMAINS AND LOCALLY, COAL; THE WHOLE ABOUT 20,000 FEET THICK APPARENTLY CORRESPONDS TO LOWER JURASSIC OF NORTHERN CHINA		
	UNCONFORMITY					
PALEOZOIC	LATE PALEOZOIC	SAIR USU SERIES	PERMIAN	LIMESTONES	A SERIES OF CHARACTERISTIC INVERTEBRATE FOSSILS	
				SHALES		
			CARBON-IFEROUS	SANDSTONES		
				SLATES		
				QUARTZITES		
				CONGLOMERATES		
UNCONFORMITY COVERING EARLY PALEOZOIC TIME						
GREAT BATHYLITHIC INVASION					MONGOLIAN GRANITE BATHYLITH	
RECOGNIZED IN PART BY EARLIER EXPLORERS	PROTEROZOIC	LATE	NANK'OU SYSTEM A NAME PROPOSED FIRST BY VON RICHTHOFEN AND GIVEN DEFINITE RANK BY WILLIS IN CHINA	THE SINIAN SYSTEM OF GRABAU	THE KHANGAI SERIES	THE TOLA RIVER GRAYWACKES AND SLATES WITHOUT FOSSILS
		EARLY	WU-T'AI SYSTEM AS USED BY WILLIS IN CHINA			SCHISTS PHYLLITES LIMESTONES DOLOMITES QUARTZITES GREENSTONES
	ARCHEOZOIC	ARCHEAN	THE T'AI-SHAN COMPLEX AS USED BY WILLIS IN CHINA			CRYSTALLINE LIMESTONES, SCHISTS, AND COMPLEX INJECTION GNEISSES

GENERAL INFERENCES

From the distribution and character of these granites and from their structural relations to the recognizable forms of the region, it is a fair inference that a great granite bathylith underlies all the country traversed by the Third Asiatic Expedition and even extends considerably beyond it in every direction. To the bathylith belong all of the large areas of granite in the Gobi region, including that which comprises Baga Bogdo of the Altai mountain system, which has been pushed up thousands of feet by later faulting. It is a fair inference, also, that most of the small occurrences, thousands of dikes and other forms of this general type preceding Jurassic time, have come from the same source and only represent the extreme outward penetration of this mass as it invaded the overlying formations.

From the facts given, it is clear that in age the bathylith is younger than any of the pre-Cambrian series, and is clearly younger than the Khangai graywackes, of whatever age the latter may be. It is clear, also, that the bathylith is so much older than the great conglomerate series judged to be of lower Jurassic age, that there was time entirely to remove the roof by erosion over large stretches of country before these conglomerates were laid down. Somewhere between the latest pre-Cambrian, therefore, on the one hand, and the early Mesozoic represented by the Jurassic conglomerates on the other, the granites invaded the overlying terrane of Mongolia. But this is a big gap,—the whole of the Paleozoic is left out of the calculation.

It is certain, however, that the graywacke-slate series was folded before the maximum invasion of granite, so that a mountain-making epoch intervened between the making of the graywacke formation and the full development of the bathylith. If, therefore, the graywackes are really latest pre-Cambrian, as now believed, time must be allowed in the Paleozoic era for this igneous invasion.

It is difficult to determine the relation to authentic Paleozoic strata, because of the very slight development of rocks of this age. Some question also arises as to the uncertainties of the age of the graywacke-slate series. The best that can be said at present is that the Paleozoic strata were not affected by the granites in those places coming under observation, and the similarity of habit in this respect to that of the Jurassic conglomerates, which are clearly very much later, leads to the tentative conclusion that the granite bathylith is itself of early Paleozoic age.

For this bathylith, which in dimensions seems to compare favorably with the greatest bathyliths thus far known in other parts of the world, we propose the name "the Great Mongolian Bathylith."

