THE
GEOGRAPHICAL
JOURNAL

VOLUME CIX
JANUARY TO JUNE
1947

PUBLISHED UNDER THE AUTHORITY OF THE COUNCIL
EDITED BY THE DIRECTOR AND SECRETARY

THE ROYAL GEOGRAPHICAL SOCIETY
KENSINGTON GORE LONDON S.W.7
JOHN MURRAY, 50 ALBEMARLE STREET, W.1.

ROYAL GEOGRAPHICAL SOCIETY

Patrons

HIS MAJESTY THE KING
HER MAJESTY QUEEN MARY

Honorary President

H.R.H. THE DUCHESS OF KENT, G.B.E., C.I.

THE COUNCIL

(*Elected* 16 *June* 1947 *for the Session of* 1947–48)
President: The Rt. Hon. Lord Rennell of Rodd, K.B.E., C.B.

Vice-Presidents

Major-General Geoffrey Cheetham, C.B., D.S.O., M.C.
The Rt. Hon. Sir George Clerk, G.C.M.G., C.B.
E. H. Keeling, M.C., M.P.
Brig. Sir Clinton Lewis, O.B.E.
Sir Harry Lindsay, K.C.I.E., C.B.E.
Gen. Sir James Marshall-Cornwall, K.C.B., C.B.E., D.S.O., M.C.

Honorary Treasurer—The Rt. Hon. Lord Catto of Cairncatto, C.B.E.

Trustees

F. M. Lord Chetwode, G.C.B., O.M., G.C.S.I., K.C.M.G., D.S.O.;
Col. Sir Charles Arden-Close, K.B.E., C.B., C.M.G., F.R.S.

Honorary Secretaries—Leonard Brooks; J. M. Wordie, C.B.E.

Foreign Secretary—Lieut.-Col. Sir John Chancellor, G.C.M.G., G.C.V.O., G.B.E., D.S.O.

Members of Council

Brig. R. A. Bagnold, O.B.E., F.R.S.
J. N. L. Baker
Sir George Binney, D.S.O.
Louis C. G. Clarke
Brig. H. Clementi Smith, D.S.O.
Colonel Sir Kinahan Cornwallis, G.C.M.G., C.B.E., D.S.O.
Augustine Courtauld
Major William Cross
Professor E. E. Evans-Pritchard
Professor C. B. Fawcett, D.SC.
Rev. W. L. S. Fleming
Dr. Violet M. Grubb
Dr. E. D. Laborde
Dr. N. A. Mackintosh
Professor Austin Miller
Mrs. Patrick Ness
Air Chief Marshal Sir John Slessor, K.C.B., D.S.O., M.C.
J. A. Steers
The Rt. Hon. Lord Tweedsmuir, O.B.E.
The Rt. Hon. Lord Wakehurst, K.C.M.G.
Professor S. W. Wooldridge

Director and Secretary—L. P. Kirwan

Librarian and Map Curator—G. R. Crone

Bankers—Martin's Bank Ltd. (Cocks, Biddulph Branch)
16 Whitehall, S.W.1

CONTENTS

NOS. 1–3 *JANUARY–MARCH* 1947

NOS. 4–6 *APRIL–JUNE* 1947

NORTH KARAKORAM: A JOURNEY IN THE MUZTAGH-SHAKSGAM AREA

R. C. F. SCHOMBERG

THE FOLLOWING brief account of a journey in the little-known Muztagh-Shaksgam area in 1945 may be of interest as so few travellers have visited this remote and unattractive country in the North Karakoram. From Phurzin-i-Dasht at the mouth of the Braldu river to the confluence of the Muztagh-Shaksgam river [1] with the stream from the Sarpo Laggo, the only previous traveller is the late Sir Francis Younghusband on the second of his Central Asian journeys in 1889.[2] Our route was from Gilgit to Baltit, the capital of Hunza; thence to the Shimshal valley, over the pass of that name, and down the Braldu river to Phurzin-i-Dasht where the Braldu flows into the Muztagh-Shaksgam river. From this point, turning right, the track led up the left bank of the Muztagh-Shaksgam as far as its junction with the stream from the Sarpo Laggo and Crevasse glaciers; then up the Sarpo Laggo to the Muztagh pass, and over to the Baltoro glacier in Baltistan. From there we ascended the Biafo glacier to the Hispar pass, and continued down the glacier and valley of that name to Nagir, and so to Gilgit.

Having reached Baltit from Gilgit, we started from there on 20 June 1945. In summer the normal way to the Shimshal is over the Karun Pir pass (15,980 feet) but, as that way was well known and decidedly dull, we chose a new route. This was by the Afdigar pass, so far unknown to Europeans, which proved however longer and more trying than the Karun Pir route, in spite of the assurance of the local people that it was quicker and easier.

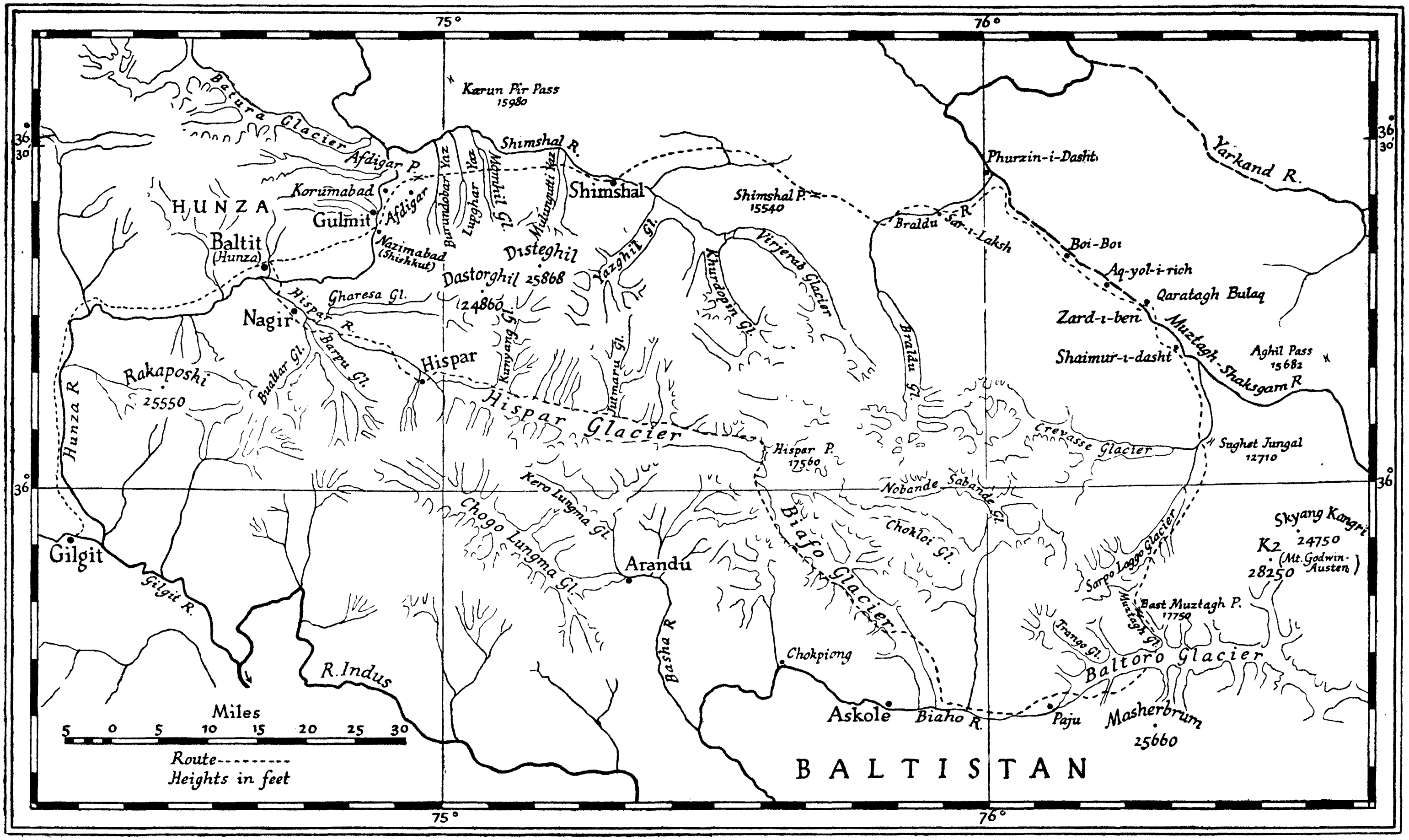
We crossed the Hunza river a little short of Gulmit by a fair "country" bridge to Shishkut, now renamed Nazimabad. From this village the track led up the left bank of the Hunza river and was extremely awkward, especially for laden coolies. These difficulties could be avoided by crossing the river by *zaq* or raft a little above Gulmit. The river is much too wide to bridge, even with a rope, but offers no difficulty to the country raft. The material for the raft would have to be brought from Gilgit. On the second day after leaving Shishkut, we made camp under the Afdigar pass, as it was impossible to reach the summit in one day from the foot. The halt was at the summer steading of Afdigar, a pleasant grassy spot with abundant juniper, grass, and a small spring, which we reached by a steady pull up over grass, offering no real difficulty.

From Afdigar camp to the top of the pass was a steady climb of four-and-a-half hours. A path had to be picked, and the track soon became very rough, with some snow, though a month later all trace of snow would have gone. The pass itself was about 15,500 feet. The view from it was very fine to the west, over Hunza proper, but looking east over the Shimshal area a dreary series of

---

[1] The river is called Muztagh, or Snow Mountain River, by the Turki-speaking people, and Shaksgam by the Tibetan-speaking people of Baltistan and Ladakh.

[2] *Proc. R.G.S.* 14 (1892) 216–18.


75°
76°
36° 30'
36°
Karun Pir Pass 15980
Batura Glacier
Afdigar P.
Shimshal R.
Burundobar Yaz
Lupghar Yaz
Momhil Gl.
Mulungutti Yaz
Shimshal
Korumabad
Afdigar
HUNZA
Gulmit
Baltit (Hunza)
Nazimabad (Shishkut)
Disteghil
Dastorghil 25868
24860
Gharesa Gl.
Nagir
Hispar R.
Barpu Gl.
Buallar Gl.
Rakaposhi 25550
Hunza R
Hispar
Kunyang Gl.
Yazghil Gl.
Jutmaru Gl.
Hispar Glacier
Khurdopin Gl.
Virjerab Glacier
Shimshal P. 15540
Braldu R.
Sar-i-Laksh
Braldu Gl.
Phurzin-i-Dasht
Yarkand R.
Boi-Boi
Aq-yol-i-rich
Qaratagh Bulaq
Zard-i-ben
Shaimur-i-dasht
Muztagh-Shaksgam R
Aghil Pass 15682
Hispar P. 17560
Crevasse Glacier
Sughet Jungal 12710
Nobande Sabande Gl.
Chokloi Gl.
Biafo Glacier
Kero Lungma Gl.
Chogo Lungma Gl.
Arandu
Basha R
Gilgit
Gilgit R.
R. Indus
Chokpiong
Askole
Biaho R.
Paju
Masherbrum 25660
Baltoro Glacier
Trango Gl.
Muztagh Gl.
East Muztagh P. 17750
Sarpo Laggo Glacier
Skyang Kangri 24750
K2 28250 (Mt. Godwin-Austen)
BALTISTAN
Miles
5 0 5 10 15 20 25 30
Route---------
Heights in feet

barren ridges filled the view, relieved however by the fine domed mountain, named Dastorghil, to the south-east. It is 24,860 feet high, and is not to be confused with its neighbour, Disteghil Sar (25,668 feet).[1]

A precipitous descent brought us tumbling headlong to the foot of the *nala* on the other side, known as the Burundobar Yaz or Shu-gardan-i-zor. The map calls it the Ghutulji Yaz, but the mixed company of local men who accompanied us had never heard of this name.[2] The *nala* itself was very narrow but pleasant, with good wood and a spring of water and room for a small camp. We attempted to follow the stream down to its junction with the main Shimshal river, but the ravine soon became impassable. There was no other course than to climb the great wall of the ravine immediately facing us. The next day we toiled up it, for a little while over grass, then over rock and shale, with patches of ice and snow. It was a wild scramble throughout, our chief troubles being the absence of a path and our guide's ignorance of the position of the actual pass. Several false casts were made, but at last, nine hours after leaving camp, we reached the crest. It was a considerably more arduous march than the previous one, over the Afdigar pass proper, and we were unprepared for it.

A very steep descent led to the Lupghar Yaz valley and glacier. On the right of the valley, near a summer grazing ground with huts, we pitched camp, thirteen hours after leaving the Barundobar. Here there were grassy slopes of a pamir-like formation and a wide and dirty glacier. Two more ridges or low watersheds had to be crossed before we joined the usual path from the Karun Pir. At last, on 27 June, we reached the village of Shimshal. The only gain from taking this unknown route was novelty. It is certainly a way to be avoided, for it offers not even a view.

From Shimshal village we had an uneventful march, over the Shimshal pass (15,540 feet) and along the Braldu river to its junction with the Muztagh-Shaksgam at Phurzin-i-Dasht. This place is a winter grazing ground on the left of the Braldu river and close to the main stream of the Muztagh-Shaksgam. Incidentally the spelling on the map, Furzid or Phurzid, is wrong. ***Phurzin*** means "birch" in the Wakhi language, and there are many birch trees here. ***Dasht*** means an uncultivated plain, and has not the significance of "wilderness" or "desert" which is given it in Persian. There was no need to cross the Braldu, so we did not visit the steading.

At this point the track turned sharp right, away from the Braldu and up the left bank of the Muztagh-Shaksgam river. Here we joined the route taken fifty-eight years ago by Sir Francis Younghusband. No European had since followed him, at which we did not wonder.[3] Immediately above the confluence of the two streams a steep and high, yellowish spur thrust into the stream. This had to be "turned" and proved a most formidable obstacle. It

---

[1] Dastorghil is the twin peak of Momhil Sar (24,090 feet) at the head of the Momhil glacier; Disteghil Sar is at the head of the Mulungutti glacier: see "Karakoram Conference report," *Geogr. J.* 91 (1938) 133.—*Ed. G.J.*

[2] The name Ghutulji Yaz was obtained from local Shimshalis by Afraz Gul on the Visser expedition of 1925, and first appears on Ph. C. Visser's map, *Geogr. J.* 68 (1926) facing p. 532.—*Ed. G.J.*

[3] Younghusband made the journey early in October 1889, when the river was easily fordable; he was therefore able to keep to the river bed throughout.—*Ed. G.J.*

was difficult and even hazardous work, and the Shimshali coolies, who are unexcelled on rock, did admirably.

There is an alternative way from Sar-i-Laksh, on the right of the Braldu river some 6 miles from its mouth, which crosses the watershed on the right of the valley by the Chinderikin pass, and joins the Muztagh-Shaksgam river from the left bank, just above the difficult part of the route where the ridge or spur ends. The Shimshalis, on their rare visits to this region, invariably take this route which, though steep and rough, is easier than following the left bank of the Muztagh-Shaksgam.

Beyond the spur, the river, which had been flowing in a gorge, became broader. The view upstream was of a wide river bed of water-worn stones, over which the turbid stream rolled and roared in its great grey channel. The bleak hills rose steeply on both sides, almost sheer from the river, and this gloomy vista was unrelieved, even the snow peaks having vanished. Indeed, the ascent of this part of the valley is in a trough, cut off from any sight of the neighbouring country.

The track went up the west side of the valley as far as a yellowish-brown hill with a domed top, known as Zard-i-ben, where our progress was checked. By climbing to a great height we could have passed over the hill, but the strain on the men was unjustifiable, and our proper course was to ferry over the river. This we did by *zaq*—a raft of skins, without which a journey in this country is impossible. Crossing back again to the left side, we continued up the valley. At Zard-i-ben there was a magnificent view to the head of the valley of Mount Godwin Austen (K.2),[1] height 28,250 feet, and its satellite Skyang Kangri (24,750 feet).

We passed several pleasant camping grounds on our way up the left bank of the valley, notably at Boi-Boi and at Aq-yol-i-rich. At the latter place there was a good deal of grass and remarkably thick brakes of thorn, with abundant tamarisk and other brushwood. There appeared to be much less vegetation of any kind on the opposite or right side of the stream. The two places named in Sir Francis Younghusband's map Yalpaqtash (the Slippery Rock) and Qaratagh Bulaq (Black Mountain Spring) could not be identified. Evidence of flooding was very marked, and it is possible that these two places had been swept away. Opposite Zard-i-ben there was a spring, and even some swamp, with a bare black mountain behind. This may have been Qaratagh Bulaq, but it seemed too far upstream to be the place named.

Just short of where the stream from the Sarpo Laggo and the Crevasse glaciers joins the Muztagh-Shaksgam, we entered the country mapped by the late Michael Spender with Eric Shipton's expedition in 1937.[2] No praise is too great for this excellent piece of cartography which provides a singularly accurate map of a very difficult area.

Leaving the main valley, the track turned up the left bank of the stream, which had to be crossed. In this we experienced great difficulty. Owing to the nature of the water, the raft could not be used, and the only means of

---

[1] The writer deprecates the label 'K.2'; if any man deserves to be commemorated, it is Godwin Austen, the first European to see the mountain. [Both names are discussed in "Karakoram Conference report," *Geogr. J.* 91 (1938) 136.—*Ed. G.J.*]

[2] *Geogr. J.* 91 (1938) 313–19, map facing p. 400.

crossing was by fording. This was cruel work. The water was bitterly cold and up to our necks; the current was strong, and the bottom of the river was rough and treacherous. The stream moreover flowed in several deep channels, and the whole manœuvre demanded both courage and care. The Shimshalis are very capable at this kind of work, and the crossing was made with only one accident. On the other side huge pots of tea restored our circulations.

From here, the route led up the western side of the Sarpo Laggo. It was very slow going, and the weather was not good. On 27 July we made camp at the mouth of the rather insignificant *nala* that leads up to the Muztagh pass (17,750 feet). The few previous travellers in the Sarpo Laggo seem to have followed the western side of the glacier and valley, which is in no way preferable to the eastern, and entails at least one unnecessary and wearisome traverse of the glacier. By keeping to the eastern side of the Sarpo Laggo much toil and temper are saved.

Crossing the Muztagh pass, that is, the East or original pass, was not nearly so troublesome as we had expected. On the Sarpo Laggo side a very easy, gentle, snow slope leads up to the crest. On the Baltistan side the descent does not at first appear to be very comfortable, but after some examination the difficulties disappear. On the left, as one looks over, there is a bergschrund and an ice fall which we at once saw to be impossible. On the right, there is a series of rough, rocky ridges covered with snow. We had an awkward scramble of some 900 feet down to the snowfield at the head of the Muztagh glacier which flows into the Baltoro. The descent is precipitous, but the dangers appear to have been magnified.[1]

The Muztagh glacier was heavily crevassed and needed some caution. But far the most trying part of the journey was the descent of the Baltoro glacier, which was most exhausting and took several days, although the actual distance is negligible. There can be no better inducement to abandon this route over the main Karakoram than the way over the Baltoro. At last we reached Paju at the snout. From there we journeyed down the Biaho to within a few miles from Askole, the first village in Baltistan, then up the Biafo, over the Hispar pass, down the valley of that name, and finally via Nagir to Gilgit.

[1] All accounts seem to agree that the Muztagh pass has become less formidable during the last fifty years.—*Ed. G.J.*

You, ladies and gentlemen, will not take it amiss if I underline—not too heavily—one of the points which Professor Wooldridge made, namely in regard to the attitude of mind to geography of geographers themselves. I think there still is in some quarters a tendency for academic geographers to apologize for being geographers. Geography has been accepted. That is the recompense for the work which has been done. The time has now come to use that acceptance as a stepping-stone towards the next stage and to cease apologizing for our existence. I myself believe this to be fundamental to the success of the campaign which will have to be waged and to which Professor Wooldridge so eloquently referred in the course of his paper. No one who has conducted a campaign has achieved much by throwing doubts on the probability of his own success, or by apologizing before going into battle for the quality of his troops and equipment.

You will all join with me in thanking Professor Wooldridge for his paper and in expressing the hope that he will again address our Society. May I repeat how glad we are to welcome members of the Association, and express the hope that this will be an oft-repeated pleasure.

Professor H. J. **Fleure**: It is my privilege to thank Lord Rennell and the Royal Geographical Society on behalf of the Geographical Association for very valuable friendship and support in geographical education. They have thrown open their doors to us, they have welcomed us here both this year and last year, and would have done so before had it not been for the war. We thank you very much, Mr. President, for this opportunity to meet the Society.

OXYGEN EQUIPMENT FOR CLIMBING MOUNT EVEREST[1]

H. L. ROXBURGH,
R.A.F. Institute of Aviation Medicine

BETWEEN 1939 AND 1945 a great deal of time was spent in producing oxygen apparatus that would enable a pilot to fly in safety up to heights of 42,000 feet. At first it might be expected that such experience could be applied directly to mountaineering where the greatest height to be gained is about 29,000 feet. On further examination however it becomes clear that there are some very important differences between the two problems. Though these differences make it unreasonable to use standard aviation equipment for mountaineering, the scientific research devoted to the production of aviation breathing equipment gives many indications of the best methods of supplying the climber. Further, a great deal of technical knowledge regarding methods of transport and storage of oxygen has become available and some equipment could, with modifications, be used on mountains.

The need for oxygen at high altitudes

In the early years of the war oxygen equipment was not provided for R.A.F. aircrew in some circumstances where it was, to say the least, desirable. In

---

[1] The writer is indebted to the Medical Directorate of the Air Ministry for permission to publish this article.

particular I have in mind flights of eight to ten hours at heights of 12,000–14,000 feet. At these heights the gross effect of oxygen shortage, such as collapse and unconsciousness, are not seen but many occurrences demonstrated that it is unwise to fly so high for long periods without the use of oxygen. Incidents reported include errors of navigation, taking unnecessary risks, releasing bombs at the wrong time, and difficulty in moving around the aircraft or loading flares into the flare chutes. As aircraft became better equipped and aircrew better trained in oxygen use, these mistakes and difficulties tended to disappear.

Let us now examine the need for using oxygen in an attack on Mount Everest. From the published accounts of attempts on Mount Everest it is evident that the physical effects of lack of oxygen were fully realized but the more intangible effects on the mind, though mentioned, do not appear to have been fully appreciated. There are many illustrations of this; an interesting one is Smythe's impression at about 28,000 feet that his companion was still with him when he had turned back with stomach trouble some time before.[1] A possible effect of anoxia which does not seem to have been described in any book on climbing is loss of insight. Many experimental subjects short of oxygen will state, for instance, that their handwriting is perfect when they are producing a meaningless doodle.

The mental effects of oxygen shortage have been repeatedly noted in unacclimatized persons and it is not unreasonable to suppose that fully acclimatized mountaineers will also exhibit them when they go beyond the height to which they are acclimatized. The determining factor in both cases is presumably a deficiency in the oxygen supplied to the brain. During an expedition to the Andes in 1935 it was shown that Europeans could become acclimatized to heights of about 18,000 feet but that above that height deterioration occurred and increased as the stay was prolonged.[2] Shortage of oxygen on high slopes is not only probably the most potent factor affecting the physical efficiency of the climber, but it also may make him careless, forgetful, and lacking in judgment and dexterity. To climb Everest without oxygen therefore would be like climbing an equally difficult and dangerous but much lower slope in a state of alcoholic intoxication. Some of the effects of anoxia are in fact very similar to those of inebriation. A man who could climb Everest without oxygen and survive would be physically and mentally exceptional and also remarkably lucky.

In order to climb Everest using oxygen, many technical difficulties have to be overcome in producing a set suitable to be carried by mountaineers. This problem is examined below.

The problem of supplying oxygen to mountaineers

The atmosphere we breathe at sea-level consists of a mixture of oxygen (21%) and inert gases which are conveniently, if somewhat inaccurately, called nitrogen (79%); these exert a total pressure of about 30 inches of mercury. As we climb, the relative proportions of the two gases remain unaltered but the pressure is reduced, so that at 10,000 feet the pressure is

---

[1] Hugh Ruttledge, 'Everest,' p. 164. London, 1933.

[2] Information communicated privately to the writer.

20·5 in. Hg., at 20,000 feet it is 13·7 in. Hg., and at 30,000 feet it is 9 in. Hg. As the oxygen we breathe is the fraction of the air essential to life, the ill effects of oxygen deficiency can be overcome by breathing oxygen or oxygen-enriched air. By doing so the unacclimatized individual can maintain full efficiency up to about 35,000 feet.

If a man breathing air is taken rapidly to 23,000 feet he will become unconscious in a period varying from five minutes to two hours and he will not be fully efficient most of that time. On the other hand, if his ascent takes days or weeks instead of hours or minutes a process of acclimatization occurs and he will be able to live at 20,000 feet for a considerable time. Above this height, as already stated, acclimatization goes no further. Acclimatization is the result of several physiological mechanisms coming into play. The ones which we must consider here are the greatly increased respiratory volume which makes respiration itself arduous, and the reduced powers of the acclimatized man to go into oxygen "debt." For comparison, when an athlete sprints 100 yards he finishes the race short of oxygen, *i.e.* in oxygen "debt," which he pays for by breathing hard for several minutes. The acclimatized man cannot to the same extent produce violent effort and make up his oxygen requirements later but must do his breathing as he goes along. The blood viscosity and the load on the heart are also increased. The height-acclimatized man is thus not so efficient as the man at sea-level.

Ideally, to climb high mountains a man should breathe oxygen-enriched air from the height at which acclimatization begins—say 5000 feet—and continue breathing it till he reaches the summit. This is not a practical proposition as he would have to spend some weeks perhaps wearing an oxygen mask, which would, to say the least, be inconvenient, and the oxygen supply problem would be considerable. Further, should the supply fail at 25,000 feet he would have no chance of survival because, unlike the airman, he would have no means of descending quickly. Thus acclimatization must be accepted as a useful—and indeed the only practical—compromise at least until 20,000 feet is reached. Oxygen may then be used so that its partial pressure in the inspired air is at least as great as it is at, say, 17,500 feet. Whether this height should be 15,000 feet or 17,500 feet or 20,000 feet is at present a matter for conjecture. The middle figure is probably a reasonable assumption. At some time the following question must be answered: Does the gain in physiological efficiency by breathing a mixture equivalent to air at 15,000 feet rather than 17,500 or 20,000 feet justify the increased oxygen load?

The remainder of this article therefore is used to discuss the provision of oxygen to more or less fully acclimatized people. An important factor to be considered is the ventilation rate of the lungs which will be grossly greater than that of the unacclimatized man. This has two important results. First, the volume of airflow through the apparatus at which resistance to respiration is first noted must be high, and secondly, unless measures are taken to mitigate it, a large amount of water, and therefore heat, will be lost in the expired gas.

Specification for oxygen equipment

The climber is limited in what he can conveniently carry by both bulk and weight. A mountaineer's oxygen equipment must therefore be both small and light and a convenient shape to carry; otherwise any physiological advantage gained by the use of oxygen may be more than offset by the encumbrance of the equipment. It should be added that, whatever the height at which oxygen is first used, the supply must be sufficient to increase the partial pressure of oxygen in the lungs at least to that at the chosen height, say 17,500 feet. With these conditions the chance that oxygen will benefit the climber is greatest. The use of inadequate quantities of oxygen should be avoided.

The following round figures are put forward as a basis for designing oxygen equipment: weight of man and equipment, 200 lb.; rate of height gain, 27·5 ft. per min.[1]; work done is therefore 5500 ft.-lb. per min. It may be assumed that where the going is easy and the above rate of climb is applicable the efficiency will not be greater than 20%, efficiency being defined as: work done/calorimetric equivalent of oxygen used above the requirements at rest. Where the going is more difficult the rate of climb and the efficiency will, of course, fall; we shall assume however that the oxygen consumption per unit time will not be altered. During descent the oxygen consumption will be reduced but the quantity necessary is difficult to estimate.

On this basis oxygen consumption measured at normal body temperature and pressure is 1·9 litres per min. What little information is available suggests that an acclimatized man using this amount of oxygen will have a ventilation volume (average volume of one breath × number of breaths per minute) of about 100 L. per min. measured at body temperature and pressure.[2] As the man inspires for only a fraction of each minute the peak rate of flow through any apparatus may be as high as 250 L. per min., again measured at body temperature and pressure.

To be successful the oxygen apparatus must in no way interfere with the respiration rhythm of the user and no appreciable work must be necessary to fill the lungs from the mask. This means that the reduction in the mask pressure below the pressure of the surrounding air at the peak rate of flow must not be great: 20 mm. of water is suggested as the maximum with the flow at 250 L. per min. This is a difficult requirement to meet but it must be emphasized that noticeable resistance to breathing may give cause to condemn an otherwise excellent apparatus. This applies particularly under conditions of acclimatization and when the apparatus is to be used for some hours. Other requirements are that the apparatus must be workable at low temperatures; it must be light, small, and reliable, and it must be simple and foolproof since the acclimatized man may be unhandy and impatient. No smell or dust must be inhaled, and conservation of moisture and heat are advantages. Oxygen should be provided for a period of six hours[3] and it should be supplied at a rate to keep the man in as good condition as if he were breathing air at 17,500 feet. It may also be an advantage to carry the oxygen in two or three containers which can be discarded when they are empty, using only one of small weight for the assault on the summit.

[1] Hugh Ruttledge, *op. cit.*, p. 218, and 'Everest: the unfinished adventure,' p. 243. London, 1937.

[2] E. H. Christensen, 'Skandinavisches archiv für physiologie,' pp. 75–6, 1937.

[3] Ruttledge, 'Everest: the unfinished adventure,' p. 244.

Methods of supplying oxygen

There are four possible types of oxygen equipment to meet these requirements: (1) a constant flow system without reservoir; (2) a reservoir system; (3) a demand valve system; (4) a closed circuit system.

A constant flow system without reservoir is so wasteful as to be ruled out immediately.

Reservoir system.—If a suitable large reservoir is included in the system, economy and reliability should result. The oxygen accumulates in the reservoir during expiration and is delivered to the face mask on inspiration. Possibly the most suitable reservoir for the purpose is a double-layer waistcoat made to a suitable volume. A waistcoat did in fact act as an oxygen reservoir in the R.C.A.F. pressure breathing equipment which was used operationally during the war (Plate 1). Another type of reservoir which was used throughout the war is the R.A.F. Economizer. Its volume (about 0·6 litre) may however be too small for use by an acclimatized man.

The oxygen flows required for either of these systems when applied to mountaineering are given in Table 1. These oxygen flows pass from the regulator (Plate 2) to the reservoir bag or waistcoat and from there during inspiration to the mask. As the lungs must complete their respiratory excursion, air must be admitted to make up the postulated ventilation volume of 100 L. per min. This is best done by spring-loaded valves in the face mask. Thus only a proportion of the inspired air passes through the tubes and resistance to breathing is minimized. With this system it would be practicable to have two settings of, say, 3 or 4 L. per min. and 6 L. per min.

Table 1.—Oxygen flows required with a reservoir system

	Alveolar partial pressure equivalent to that at			
	17,500 *feet*		20,000 *feet*	
Actual height (feet)	*% total* O_2 *necessary in inspired gas*	*Added* O_2 *L./min. N.T.P.*	*% total* O_2 *necessary in inspired gas*	*Added* O_2 *L./min. N.T.P.*
25,000	30	3·2	27	2·5
29,000 [1]	38·5	6·1	34	5·5

The system is however uneconomical owing to the fact that less than half of the inspired oxygen (30–40 per cent. under the conditions considered) is absorbed in the lungs, the remainder being lost in the exhaled air together with an appreciable quantity of water vapour and heat. To maintain both heat and water vapour some form of heat-retaining device, such as the Matthews respirator, must be considered.

Demand valve system.—A demand valve (Plate 3) is a regulator which supplies oxygen, or a mixture of air and oxygen, when suction is applied to it. The user thus gets a supply of gas in proportion to his needs. It can be so arranged that the mixture delivered is adjusted to the altitude: the percentages required are shown in Table 1. A system of this kind requires a good mask fit.

---

[1] It is the pressure at the top of Mount Everest which is important physiologically. Under certain weather conditions this may be less than the standard value for a height of 29,000 feet.

It is difficult to estimate the consumption of oxygen over a given period but there is no doubt that the physiological requirements of the user are well covered. As in the reservoir system, the oxygen breathed out is lost and there is again the loss of water vapour and heat. Of the two systems the demand valve is probably the lighter.

Closed circuit systems.—To overcome this waste, systems have been developed whereby the exhaled oxygen re-enters the lungs. This entails the removal of carbon dioxide from the expired gas and the exclusion of inert gases from the system. Almost pure oxygen is therefore breathed, the carbon dioxide being removed by the gas passing over soda lime in a sheet-metal canister. A reservoir, equivalent in volume at least to a deep breath, must be placed in the gas circuit.

With this system oxygen disappears only in so far as it is absorbed by the lungs. The oxygen used may be replaced by a constant addition or, better, by a demand valve arrangement similar to that described above, supplying pure oxygen only. This allows great economy of oxygen but the saving in weight is largely nullified by the amount of carbon dioxide absorbent necessary; for in order to reduce back pressure through the canister to reasonable proportions it is necessary to have a fairly large particle size and the soda lime will then absorb only about 40 per cent. of the theoretical amount of carbon dioxide. Thus a large weight of absorbent is necessary for our postulated oxygen consumption: five or six 3 lb. canisters will in fact be needed. With development, and by the use of two or more canisters together, this weight may be reduced but the reduction is unlikely to be great until an absorbent with greater efficiency (in terms of weight of carbon dioxide absorbed per unit weight of absorbent) can be found. It must be remembered that soda lime canisters should be hopper-filled to ensure even, tight packing and the contents held in place under spring pressure so that dust does not form in transit. The canisters will not operate efficiently at very low temperatures.

With this system, loss of heat and moisture are small but it has a number of disadvantages: (*a*) a perfect mask fit is required; (*b*) mask and tubing must be large and heavy since oxygen must be led to and from the mask and each lead must be fitted with a non-return valve; (*c*) the resistance to breathing may be great; (*d*) it is possible that the apparatus may become blocked by condensation of the moisture from the expired oxygen. This type of apparatus has been tried and has failed on Mount Everest though it passed all tests with unacclimatized subjects, and it is considered impractical for use in the R.A.F.

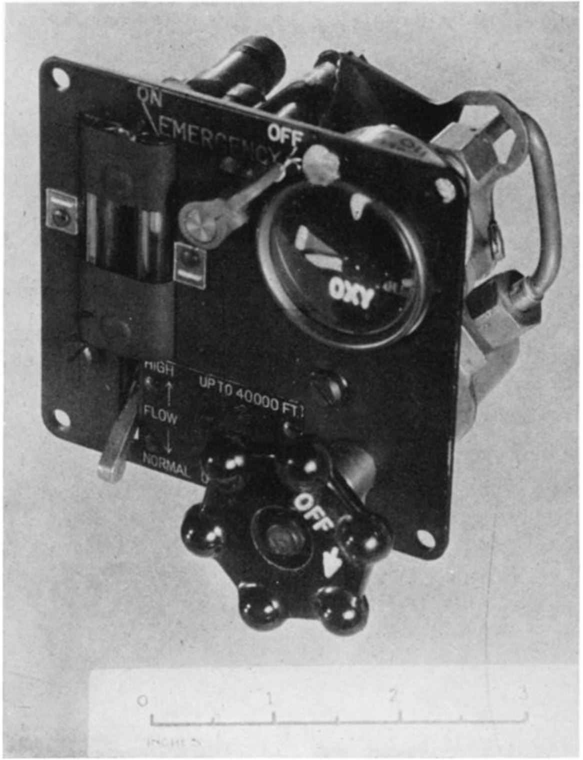
In a letter to *Nature* in 1939 [1] the then most up-to-date oxygen apparatus of the closed circuit type was criticized by Lloyd because it caused a feeling of suffocation after being used for a short period—in spite of passing all tests at ground-level and on the Alps. The cause of this feeling of suffocation was probably not only lack of oxygen, though the possibility of leaks must be considered. More likely causes were, first, the reservoir bag being too small and causing "bottoming" at high volumes; second, carbon dioxide being insufficiently absorbed, due possibly to the high velocity of gas through the absorbent or to layering of the soda lime or to the low temperature; and third,

---

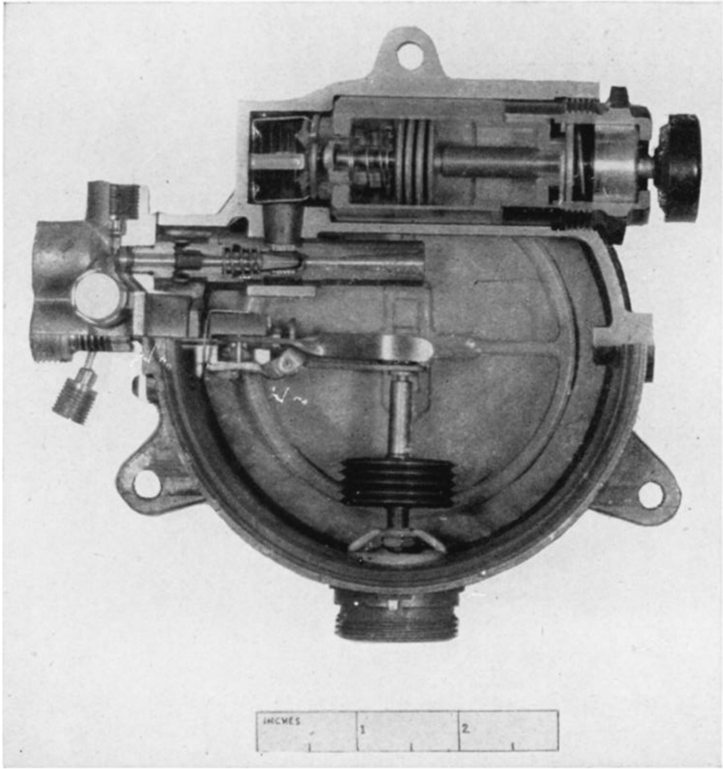
[1] Peter Lloyd, "Use of oxygen on the Mount Everest Expedition 1938," *Nature*, 143 (1939) 961–3.

Phots. Crown Copyright Reserved

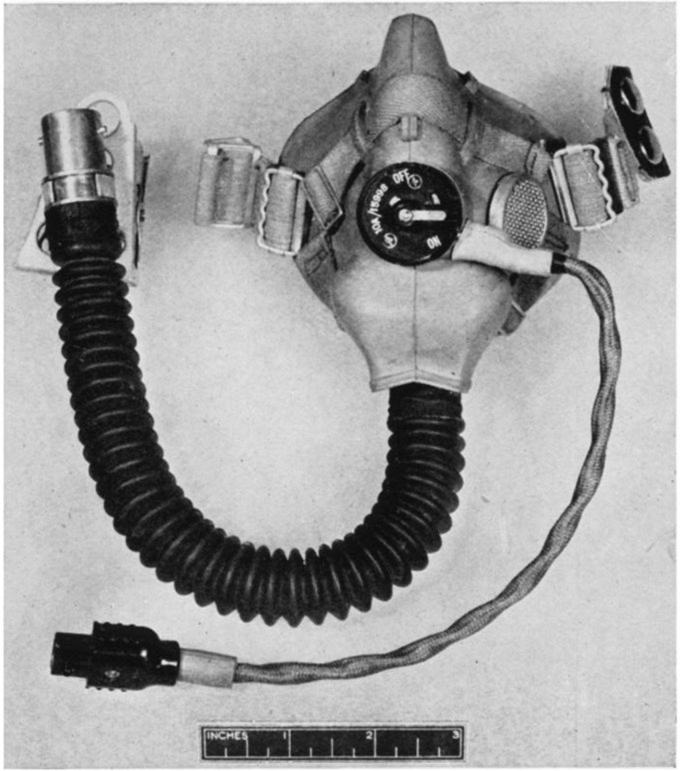
1. R.C.A.F. pressure waistcoat used operationally during the war as an oxygen reservoir and to apply pressure to the chest at altitudes above 40,000 feet



2. R.A.F. Mark XI regulator designed to supply oxygen at rates of 3 or 6 litres per minute



3. German demand valve used by the Luftwaffe, in section



4. R.A.F. oxygen mask type H, the most efficient mask in use by the R.A.F., incorporating a microphone and most important, the back pressure at high instantaneous rates of flow being great enough to cause resistance to breathing. The man using a re-breather system has a pressure of oxygen in his lungs greater than that normal at sea-level. It has been suggested therefore that the use of a closed circuit system could cause loss of acclimatization or other disturbance, and be dangerous in case of failure. The truth of this is not known, but it is considered unlikely that an effect of this nature would be appreciable during the time the apparatus is in use.

The development of an efficient closed circuit apparatus for mountaineering is therefore a complex problem which will not be solved without vigorous experimental work and testing under realistic conditions.

Methods of carrying oxygen

Oxygen can be carried (1) as a high-pressure gas, (2) as a liquid, or (3) chemically combined with other elements. At present the simplest form for storage and carriage of small quantities of oxygen is probably high pressure gas. Cylinders are robust and reliable and leakage can be extremely small. The cylinder weight however is great; that is, it is three times the weight of the contained gas if cylinders are used and about twice the weight if spheres are used. The control of oxygen delivery is also simple.

Under many circumstances the ideal way of carrying oxygen is in the liquid form. Liquid oxygen boils at −183° C. at 1 atmosphere pressure and must therefore be carried in thermally insulated containers such as vacuum flasks. As the container cannot withstand the great pressures developed in a closed space, it must be open to the atmosphere or have a suitable safety valve. Because heat leaks into the containers there is a steady evaporation of oxygen; the loss is appreciable and in small containers where the surface to volume ratio is great the percentage loss is high. For use in mountaineering therefore it would be necessary to fill the portable liquid containers from the main store shortly before using them.

Under certain circumstances it is possible to reduce this loss. For instance, if the container is designed to operate at a moderate pressure (say 50 lb. per sq. in.) the loss can be zero until this pressure is reached and while the heat gained by the liquid is merely raising the pressure in the vessel. Large-size containers of this type have been used in aircraft and show no loss of oxygen for about 30 hours after filling. The pressure can, of course, be raised in a much shorter time should this be necessary. When in use, the oxygen passes from the container to an evaporator coil and thence to a regulator which is able to operate at low pressures (say 50 lb. per sq. in.).

When mountaineering, if the time between leaving the base camp and making the actual assault on the summit is long, the use of liquid oxygen is probably impracticable. But since this is by far the lightest way of carrying a certain amount of uncombined oxygen its possibilities should be investigated carefully.

Several methods of storing oxygen in a chemically combined state have been used experimentally. One method is particularly worthy of attention and with development it may become the most useful for climbing. Potassium tetroxide is a substance which, under suitable circumstances, has the properties not only of giving up oxygen but also of absorbing carbon dioxide. It may thus be practicable to produce for mountaineering a chemical re-breather demand system in which the absorption of carbon dioxide causes the liberation of oxygen. More oxygen is produced than carbon dioxide is absorbed so that the system is self-flushing. The oxygen is produced warm, which has advantages under sub-zero conditions. As the one canister can act both as liberator of oxygen and absorber of carbon dioxide and as no regulators or high pressure unions are involved, the sub-division of the oxygen supply into two, three, or four small units should be simple; this is impracticable with the other systems and is an important point.

Candles using sodium or potassium chlorate as a source of oxygen have also been used extensively. They are reliable, have a good store life, and are safe in use. The weight of oxygen delivered is about one-third the weight of the chemical mixture used. The rate of production of oxygen for any given candle is determined by the geometry of the candle and is not controllable by the user.

Some of the particulars given above are tabulated in Table 2.

Adaptation of existing equipment

Any good aviator's mask should be satisfactory. It must have fairly low resistance to flow and good anti-freeze properties combined with sufficient sizes to fit most faces. The individual should be allowed to choose the one that fits him best. The R.A.F. mask type H (Plate 4) and R.C.A.F. mask are probably as good as any. For a re-breather circuit, modification of the mask will of course be necessary. A problem is the provision of suitable masks for bearded men. If the beard is thick it is difficult to obtain a gas-tight fit. The easiest solution is to trim the beard or, better still, shave it off.

Mask tubing should be of wide bore, unkinkable, and designed for small back pressure; the shape of corrugations can have a profound influence on the resistance to air-flow. For intermittent flow systems the R.A.F. Mk. IV tube is satisfactory. Wider tubing is probably necessary for re-breather circuits.

A reservoir oxygen system of type 2, efficient in all respects except weight and bulk, could be made from parts that are now standard and available: *i.e.* five light-weight steel spheres, total capacity 2030 litres N.T.P., weight 12 lb.; oxygen, 6 lb.; Mk. XI regulator (modified to give suitable flows), 2 lb.; R.A.F. Economizer, 2¼ lb.; R.A.F. Oxygen Mask type H, Mask Tube type IV, ½ lb.; piping, framework, etc., 3 lb.; total, 26 lb. The oxygen mask should be provided with two air inlet valves to reduce inspiratory effort at high rates of flow. A reservoir system of type 3 could also be made from available parts: five cylinders (as above), 12 lb.; oxygen, 6 lb.; demand valve, 2 lb.; mask, mask tube, framework (as above), 3½ lb.; total, 23½ lb.

To produce a light-weight oxygen apparatus to meet fully the specification laid down is however not so easy though the experience gained during the war would no doubt be of great help.

Summary of proposed research

Investigations should proceed on the following lines. First, the physiological requirements which have been postulated for the purposes of this

Table 2.—Particulars of oxygen systems which might be suitable for mountaineering

System	*Flow rate (litres N.T.P.)*	*Weight of total oxygen (lb.)*	*Weight of containers (lb.)*	*Weight of regulator (lb.)*	*Weight of CO_2 absorbent if any (lb.)*	*Total weight (lb.)*	*Type of mask*	*Remarks*
I. Intermittent flow or demand valve	6	7	14 (as H.P. gas) 7 (as liquid)	1¾	Nil	25 18	R.A.F. H type	1. Alveolar oxygen tension equivalent to 17,500 feet. 2. Loss of water and heat great. 3. Simple to operate.
II. Re-breather with carbon dioxide	2	2¼	5 (as H.P. gas) 2¼ (as liquid)	Unknown	15	24 21	R.A.F. H type with 2 tubes.	1. Alveolar oxygen tension above ground-level value. 2. Minimum loss of heat or water. 3. Possibility of dust or smell from absorber. 4. Complicated.
III. K_2O_4 re-breather	3	10 (as K_2O_4)	Unknown (small)	Nil	Nil	15	R.A.F. H type.	1. Alveolar oxygen ground-level value. 2. Loss of water minimal. Heat gained from chemical reaction. 3. Self flushing. 4. Sub-division of load possible. 5. Resistance to breathing probably great.
IV. Chlorate candle with intermittent flow	6	21 (as chlorate mixture)	Unknown	Nil	Nil	30	R.A.F. H type.	1. As I but gas may be delivered hot and wet. 2. Sub-division possible.

article should be scrutinized and, if possible, tested under realistic conditions. Second, experienced mountaineers must decide such problems as the necessary duration of the supply and the desirability of using oxygen while descending. Third, the carriage of oxygen as a liquid should be studied. Research on the use of liquid oxygen for R.A.F. purposes has been concerned with containers for large aircraft. Information gained regarding methods of flow regulation might be applied directly to small portable containers.

The production of a closed circuit apparatus with low resistance to airflow should also be examined. The Royal Air Force used no closed circuit apparatus during the war, as its complexity and the difficulty of maintenance did not justify the saving in weight of oxygen. Systems of this type suitable for unacclimatized men working at high rates have however been developed. The system used for underwater purposes by the Royal Navy is of this type; whether it would be suitable for acclimatized men is a matter for investigation.

Finally, consideration must be given to potassium tetroxide as a source of oxygen and carbon dioxide absorber. Theoretically a closed circuit system using this substance would be lightest: it has no moving parts, it retains water vapour and heat, and it permits sub-division of the load to be carried.

PORT AND OUTPORT IN NORTH-WEST EUROPE

N. J. G. POUNDS

THE RELATIONSHIP between the port at the head of an estuary or at the tide limit and the port at the river mouth has become sufficiently familiar to justify the use of the terms "port" and "outport." This relationship—in some instances complementary, in others amounting almost to rivalry—has been established in the course of the last two or three centuries. The balance between port and outport has changed and in some cases is still changing. And each "pair" of ports is not strictly comparable with every other pair. Local conditions of waterway and tide, local specialization in certain commodities, concentration on trade with certain countries or continents, vested interests of shipping firms, municipal corporations, and political bodies have assisted or retarded the growth of outports, enabling them to conform in greater or lesser degree to what I shall later define as the normal pattern of relationship between port and outport.

The medieval ports of north-western Europe lay, with very few exceptions, near the tide limit of rivers at points which could be reached, not always without difficulty, by the largest vessels of the time. London, Chester, Bristol, Bordeaux, Nantes, Rouen, Bruges, Bremen were thus placed. A few, such as Hull and Plymouth, lay closer to the sea but these were not then of the first importance. All the estuary-head ports named have since been duplicated by outports. In some instances the port has suffered an absolute decline, even extinction; in others, its decline has been relative only.