

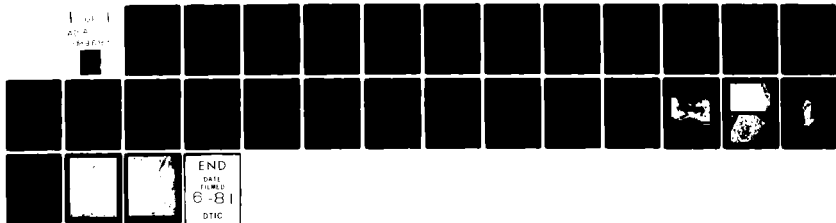
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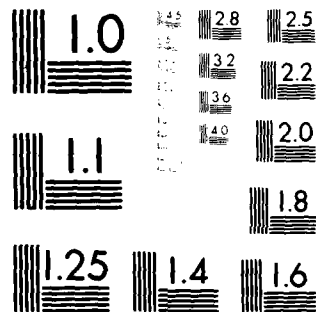
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6 MODES OF THERMAL PROTECTION IN POLAR BEAR CUBS - AT BIRTH AND UPON EMERGENCE FROM THE DEN,

By

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BLIX, A. S. and J. W. LENTFER. Modes of thermal protection in polar bear cubs - at birth and upon emergence from the den. Am. J. Physiol. At birth in late December the polar bear is small (700 g), uninsulated and helpless. It probably has a modest capacity for metabolic heat production and depends on the female and a snow den in which it is born for thermal protection. The microclimate of an artificial polar bear den was investigated at Point Barrow, Alaska, and the temperature therein found to stay around 0°C provided a heat source (200 W) equivalent to an adult polar bear was introduced. When the bears desert the den in early April the cub has grown to about 10 kg and has a well developed fur insulation, but almost no subcutaneous fat. The cub has a high resting metabolic rate (14.2 ml/min/kg) which is supported by the fat polar bear milk. Its lower critical temperature is about -30°C, and an ambient temperature of -45°C results in only a 33% increase in metabolism. The cub can tolerate a windchill of 2000 kcal/m²/h without apparent stress or drop in rectal temperature. If the cub is immersed in ice-water rectal temperature drops 11°C in 30 min. It is concluded that the cub can tolerate extremely low temperatures in air due to fur insulation and high metabolic heat production, but is unable to cope with the chill of ice-water for any prolonged period of time,

Ursus maritimus, temperature regulation, cold tolerance, metabolism, windchill

Project: Polar Bear	Specimen No.:	Collector:	Date:
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POLAR BEARS (*Ursus maritimus*) give birth in snow dens in December, when outside temperatures often are below -40°C . Occasionally, polar bears have given birth in captivity, and the newborn cub has been described as small (6-800 g), blind, and sparsely haired (10).

Knowledge of the natural den microclimate is scanty. Temperatures of -10°C (7) and -18°C (8) have been reported from dens in Canada. Temperatures well below zero (-5 to -13°C) have also been reported by Belikov (1) from the Soviet Union. Although these records hardly reflect the microclimate near the newborn cub they undoubtedly point to a rather cold environment.

We recently had the unusual opportunity to examine two newborn polar bears and found it very unlikely that they can cope with severe cold stress. Since true polar bear den temperatures are very difficult to obtain, we examined the microclimate of an artificial den of typical polar bear construction. Quite in contrast to the low temperatures recorded by Harington and Belikov (1, 7, 8), we found that the temperature of the den probably stays near freezing provided the female is inside. In Alaska the polar bear will usually desert the den by early April, when ambient temperature occasionally drops to -30°C . This implies that the cub upon emergence might be subject to a thermal gradient similar to the one experienced at birth. Consequently, the present report also deals with the modes of temperature regulation which are employed during this second critical period in polar bear life. The tolerance to different environmental stresses in this species has also been given some consideration.

MATERIAL AND METHODS

Three polar bear cubs (*Ursus maritimus*) were used in this study.

Two cubs were born quite unexpectedly (27 December) at an ambient temperature of -45°C in an outdoor uninsulated cage which provided only protection from the wind. One (female) died two hours after birth, while the other (a male) survived for two days at the same ambient temperature. Both cubs were frozen immediately post mortem and kept in a deep freezer until the start of the present investigation.

After thawing the cubs were measured and weighed. The weight/surface area relationship of their bodies was estimated by way of integrated circumference measurements and weighing. Morphological characteristics potentially relevant to temperature regulation were visually examined. Fat and skeletal muscle (m. psoas and m. latissimus dorsi) were excised and prefixed in 2% glutaraldehyde for 3 h. The samples were then kept in 0.1 M cacodylate buffer for 1-5 days, post-fixed for 2 hr in 1% OsO_4 , dehydrated in ascending grades of ethanol, and finally embedded in plastic (14). Sections were cut in a Sorvall Mt-2 ultramicrotome and examined in a JEM-6AS electron microscope. The hair density of the fur of one cub was determined as number of hairs/ cm^2 under a light microscope.

One cub was captured off Point Barrow, probably within a few days after emergence from the den (29 March). The cub, a male, was kept in an indoor pen at about -5°C for the next 10 days. It was fed four times a day with a 1:1 mixture of whipping cream (30% fat) and milk. It was able to drink from a bowl immediately upon capture.

The cub was kept for three days before any experiments took place. In this period it grew very tame and it was programmed to stay awake during the day and sleep in darkness during the night. Thus, it was fed only during the day.

The cub's metabolic response to different ambient temperatures was tested in a series of three experiments, each carried out on different days and lasting for about 10 h. The experiments started at 2000 h and the cub always fell asleep within 30 min after being transferred to the metabolic chamber. An open flow system was employed. A Beckman G-2 oxygen analyzer was used for measurements of oxygen consumption, and a Beckman Model 864 CO₂ analyzer monitored the CO₂ concentration in the chamber. Both instruments were calibrated with gases previously analyzed with a Scholander 0.5 cc gas analyzer (15). The flow rate was maintained at about 26 l/min, and the CO₂ concentration of the outlet air did not exceed 0.5% during steady state conditions. The deep body temperature of the cub was monitored throughout the experiments with a MiniMitter[®] thermosensitive radio-transmitter swallowed by the cub prior to the first experiment.

The cub was exposed to a temperature ranging between -30 and -35°C (on average -32°C) and a constant wind (furnished by a fan) of 8m/sec for 4 h. During this experiment its deep body temperature was followed by use of a thermocouple rectal probe inserted 16 cm into the rectum. The experiment was carried out once.

The cub's deep body temperature response to immersion in ice water (0-2°C) was followed by use of a thermocouple rectal probe inserted

16 cm into the rectum. As an additional measure the transmitter used in the metabolism experiments was also employed. Precautions were taken to prevent drinking of cold water. This was the last experiment to be executed. The animal was exposed to ice-water only once.

The cub was killed and bled. Morphological characteristics potentially relevant for temperature regulation were visually examined. Fat (subcutaneous and internal) and muscle (m. psoas and m. latissimus dorsi) were excised and processed for electron microscopical examination as described for the newborn cubs.

In order to investigate the microclimate in a polar bear den, we dug a den of the typical shape and location (13) in a snow drift at Point Barrow, Alaska. The den was instrumented with thermocouples at two locations and equipped with a 200 w light bulb which is equivalent to the heat produced by an average size female polar bear (N. A. Øritsland, unpublished results). A sketch of the experimental set-up is presented in Fig. 1. After completion of the experiment the snow around the den was tested for density, hardness and temperature with standard CRREL snow measuring equipment (2). A number of snow samples from known denning areas at Colville River (Miloveach) and Dease Inlet (Kugorak Bay) were also collected and tested for comparison with those from the artificial den at Barrow.

RESULTS

The external features of a newborn female polar bear cub, which died only two hours after birth is shown in Fig. 2. This cub weighed 673 g, while the male twin cub survived for two days and weighed 580 g at the time of death. The surface areas of the male and female were estimated to 790 and 834 cm², respectively. The fur on the dorsal side had 650 hairs/cm², and the length of the hairs was 5 mm. Both cubs were blind and without teeth, but had conspicuously large tongues.

Autopsy revealed no subcutaneous fat and internal deposits of fat were only found on the kidneys in very small amounts. Electron microscopy revealed that the cells in the extra-renal (adipose) tissue had large nuclei and ample amounts of mitochondria (Fig. 3A), which are the typical features of brown adipose tissue (9). The skeletal muscles of the cubs were partly damaged by freezing, and their mitochondrial content, which might serve as an indicator of possible non-shivering thermogenesis (6), could not be identified with certainty. It was evident, however, that both muscles investigated contained much glycogen, which is the case in most newborn mammals (5). A micrograph of a muscle section showing glycogen deposits between the filaments of muscle fibrils is shown in Fig. 3B.

Due to dissipation of heat from the earth a certain thermogradient is found in the snowdrifts which are utilized by polar bears for den construction. Thus, in an 8 foot deep drift on the bank of a freshwater lake with 2 m ice-cover in the Dease Inlet area, we found the temperatures

at 1, 4, and 8 foot depths to be -27 , -22 , and -7°C , respectively, at an ambient temperature of -29°C . The snow density was 0.3 g/cm^3 , and the hardness varied between 2000 and 8500 g/cm^2 . A six foot deep drift with similar density and hardness formed on gravel in the denning area of the Colville River delta had at the same ambient temperature a snow-gravel interface temperature of -19°C . It is evident, therefore, that heat from the ground or water beneath the ice could be utilized for heating of polar bear dens, but relatively few dens are found on sea ice (12) and most dens examined have had a layer of snow between the dens and the ground (11, 13).

An artificial den of typical polar bear design was dug on a 9 foot deep drift at Point Barrow (Fig. 1) in order to investigate how the microclimate of its interior is affected by the presence of the adult bear. The snow density of the drift varied between 0.3 and 0.4 g/cm^3 and hardness varied between 2500 and 25000 g/cm^3 . This variation in hardness was not directly related to depth in the drift, but was most likely caused by different weather conditions in the period between consecutive snowfalls.

Three thermocouples were mounted to record den temperatures at two locations and ambient temperature outside the den. A light bulb controlled from outside the den was finally put into the den to simulate heat produced by bears in a natural situation (for locations see Fig. 1). With the entrance to the den sealed with snow the light bulb brought the temperature inside up to above freezing in four days at an ambient temperature varying between -35°C and -30°C . With the temperature under

the ceiling at 6°C and the floor at 0°C a steady state situation was established. The entrance to the den was then opened as occurs in natural dens late in the denning period. This resulted in an almost instantaneous drop of floor temperature to about -5°C (at an ambient temperature of -30°C), while the ceiling temperature dropped only one degree to 5°C. After three days without further changes in the den temperatures at a constant ambient temperature of -30°C the light bulb was turned off. In less than three hours after removal of the heat source the thermal gradient between the ceiling and the floor of the den disappeared and the temperature at both sites rapidly approached the temperature of the surrounding snow. Inspection of the den then revealed that the snow in the ceiling had melted to some extent and that a 0.5 to 1 inch layer of ice had formed.

Polar bears usually desert the den in late March or early April in Alaska. At the time of emergence the cub has more than doubled its birth weight about four times and developed a relatively dens pelt which even covers the paws. The cub used in this study was caught 29 March and weighed 8.9 kg upon capture and gained 3.6 kg during the ten days it was held in captivity. During this period of time it grew very tame (Fig. 4).

The oxygen consumption of this 12.5 kg polar bear cub at ambient temperatures from -15°C to -45°C is shown in Fig. 5. Resting (sleeping) metabolic rate in the thermoneutral zone was 14.2 ml/min/kg and lower critical temperature was -30°C (Fig. 5).

A further reduction of ambient temperature to -45°C which is much lower than a cub is likely to encounter after emergence from the den, resulted in only a 33% increase in oxygen consumption. It is also noteworthy that an oxygen consumption similar to that recorded while still in the thermoneutral zone was obtained for one hour while the cub was sleeping at an ambient temperature of from -40°C to -42°C . During this period deep body temperature did not decrease.

Upon exposure to temperatures ranging between -30°C and -35°C (average -32°C) and a constant windspeed of 8 m/sec, which gives a windchill of $2000 \text{ kcal/m}^2/\text{h}$ (3) the cub responded with a curled up posture [described by Øritsland (21) as posture III] and a slight shivering, but without a drop in rectal temperature. Aside from occasional mild vocal complaints, the animal showed no sign of distress or frostbite. The observer's hand, however, was frostbitten after 30 sec exposure to the air-stream.

When the cub was immersed in ice-water it tried vigorously to get out. In spite of this activity, its rectal temperature dropped 11° in 30 min (after which it was taken out and reheated in warm water). The ice-water exposure obviously led to complete wetting of the fur. The animal was shivering even with rectal temperatures around 30°C . Reheating of the cub in water of about 40°C took 35 minutes. The cub was very active also during this procedure.

The cub was then killed and bled. Autopsy revealed a thin 1-2 mm subcutaneous layer of fat and modest deposits of fat on the pericardium and along the coronary arteries and thoracic ribs. The abdominal cavity,

on the other hand, was rich in fat. The kidneys were almost buried in fat and great amounts of fat were found in the mesenteries. Only small deposits were present between the muscles of the shoulders. Although a few cells with a relatively rich supply of mitochondria could be found in the internal fat deposits, the general electron microscopical appearances of both the internal and subcutaneous deposits were those of white adipocytes. The electron microscopical examination of the skeletal muscles revealed an abundant supply of mitochondria and glycogen, but a low concentration of fat (Fig. 6).

DISCUSSION

Our studies of a man-made den of typical polar bear design indicate that the temperature inside polar bear dens, contrary to previous assumptions (1, 7, 8), stays at or slightly above 0°C which of course is the highest temperature that can be maintained without extensive dripping from the ceiling. In support of our findings are several reports (11, 13) of ice-crusts of more than one inch in thickness in the ceilings of natural polar bear dens.

Our studies of newborn polar bears were not carried out on live animals and we can only speculate as to their modes of thermoregulation and ability to cope with the relatively chilly microclimate of the den. We know that the polar bear at birth is small and very undeveloped. Its surface area/body weight ratio is not particularly unfavourable, but its fur is short and sparse and subcutaneous fat is missing. According to Tregear (19), such pelts admit an extensive radiative heat loss to take place, instead of offering significant insulation.

We know that brown adipose tissue is present extra-renally, but the amount of it at birth is insignificant for thermoregulatory purposes. In an animal so undeveloped at birth that it takes 30 days for the eyes to open and a similar period of time before it can stand on its feet (10) it is also unlikely that shivering is of much importance. This view is supported by the fact that the muscles of the cubs still contained large amounts of glycogen (Fig. 3B) at the moment of their deaths. Date of birth, body weight and size and general appearance are similar for

our cubs and six cubs born and raised in Leningrad Zoo (10). It is therefore likely that our description reflects the true features of newborn animals. How can such creatures survive and even double in weight four times in three months at ambient temperatures close to freezing? According to Kost'yan (10) the female polar bear lies in a curled posture and holds the cubs to her breasts and thereby provides them with the insulation they lack at birth. Cook et al. (4) have further reported that polar bear milk contains more than 30% fat even after about a year of continuous lactation. We believe that the high energy content of the milk supports a high resting metabolic rate and that this together with the insulation provided by the den and the long dense fur and posture of the female accounts for the survival of the cub in the first few critical days. Decreased deep body temperature as an additional mode of energy conservation seems remote, but can not be discounted completely. The importance of the den was clearly demonstrated by the cubs which froze to death when born outside the den. On the other hand, the cub which stayed alive for two days revealed the potential of the other factors involved.

The polar bears on the arctic coast of Alaska usually emerge from the dens in late March or early April when weather can still be severe. During the present study (1-10 April) the average temperature was -30°C (range -25 to -35°C), while the 50 year average for the same period is -22°C . At the time of emergence the cubs have acquired a weight of about 10 kg and are insulated with fur which even covers the paws with a dense pad of hairs. We were not able to measure the metabolic rate of

newborn cubs, but the metabolic rate of our three month old cub was high (14.2 ml/min/kg). The high metabolic rate at rest and the superior insulation together give the cub the remarkable lower critical temperature of -30°C . It is, moreover, noteworthy that metabolic rates comparable to those recorded under thermoneutral conditions were maintained for about one hour at temperatures well below the lower critical temperature (Fig. 5). This can be explained as a result of peripheral cooling, a phenomenon we also have observed in young fur seal (Callorhinus ursinus) pups from Pribilof Islands, Alaska (2).

Our cub's outstanding tolerance to dry cold was further demonstrated when an unnatural drop in ambient temperature to -45°C resulted in only a 33% increase in metabolic rate. This can easily be accounted for by light activity as shown in our plot (Fig. 5). Further evidence of the cub's cold resistance was acquired from the windchill tolerance test. Here the animal was exposed to a windchill of $2000 \text{ kcal/m}^2/\text{h}$, equivalent to approximately -80°C in still air without a decrease in rectal temperature. Slight shivering was observed during the test. Measurements of metabolic rate of polar bears of similar weight as our cub have previously been made by Scholander et al. (17), who found a 26% lower "basal" metabolic rate and a lower critical temperature of only $+2^{\circ}\text{C}$. In the same study the lower critical temperature of two Eskimo dog pups of similar size from the same area as the polar bears were found to be below -30°C , which was the lowest temperature reached. Unfortunately, they do not discuss these odd results or describe the duration or conditions of their study. We will therefore regard the lower critical temperature

they reported for polar bear cubs as wrong. We furthermore believe that the cubs at the time of emergence from the den can cope with any expectable weather as a result of a high metabolic heat production supported by the high energy of the polar bear milk (4) and outstanding fur insulation.

When our cub was immersed in ice water, on the other hand, its rectal temperature dropped very rapidly in spite of vigorous activity associated with attempts to get out of the water. Occasionally we have observed cubs riding on the female's back across open leads shortly after their emergence from the den. Based on our experiments, however, we find it hard to believe that cubs can tolerate much more than 10 min exposure to ice water without passing the thermal point of no return if the weather as usual is very cold. However, 10 min allow for crossing of fairly wide leads and in 10 min the cub's deep body temperature will drop only to about 35°C. The cub is fully capable of shivering and exercised a high level of activity even with a deep body temperature of 30°C. This in combination with the polar bear fur's amazing ability to relieve itself of the water and thereby regaining its insulative value when shaken in air probably account for the cub's apparent tolerance to short exposure to ice water under natural conditions. Scholander et al. (16) measured the insulative value of polar bear pelts and found it to be reduced by more than 90% if the pelts were exposed to ice water. The insulative value of a cub pelt is obviously lower than those of adult winter pelts, and consequently the cub pelt hardly offers any significant insulation when exposed to ice water. Autopsy of the cub exposed very little subcutaneous fat. Thus, it is apparent that the cub will encounter

problems in maintaining body temperature when the fur insulation is reduced by ice water. Brown adipose tissue is known to be an important site for non-shivering thermogenesis in many newborn and juvenile mammals (18). As reported above we discovered small amounts of such tissue in the newborn polar bear cubs, but at the time of emergence from the den no deposits of brown adipose tissue could be identified. Most likely therefore it is important only for a certain period during the stay in the den. Recently, Grav and Blix (6) have demonstrated that the skeletal muscles of the fur seal (Callorhinus ursinus) might act as important sites for non-shivering thermogenesis. The electron microscopic examination carried out on the skeletal muscles of the three month old polar bear cub revealed a high concentration of mitochondria which is one of the prerequisites for non-shivering thermogenesis. The mitochondria found in the muscles of the cub had a low content of cristae and unlike the mitochondria of the fur seal they were not usually associated with fat droplets. This makes the muscles of the polar bear cub more like those of the newborn beluga whale which presumably has to increase its heat production through shivering and swimming (Blix, unpublished).

In conclusion, therefore, it seems that the high metabolic rate and the outstanding dry fur insulation are the main factors allowing the polar bear cub to survive in their high arctic habitat.

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LEGEND TO FIGURES

- Fig. 1. Artificial polar bear den dug by man at Point Barrow, Alaska, in vertical (upper sketch) and horizontal (lower sketch) section. The localization of three thermocouples (1, 2, & 3) and a heat source (O) are indicated.
- Fig. 2. Polar bear cub, born 27 December, aged only two hours. Nose to tail length is 34 cm and weight is 673 grams.
- Fig. 3A. Electron micrograph of extra-renal deposits of fat from newborn polar bear. A large nucleus (N) and dense aggregates of mitochondria (M) are visible. The triglyceride content of the cell is probably exhausted after severe cold exposure and only a few droplets of fat can be seen.
- Fig. 3B. Electron micrograph of the psoas muscle of newborn polar bear cub. Glycogen granules are seen between the filaments of the muscle fibrils.
- Fig. 4. Polar bear cub at the time of emergence from the den (photo taken 8 April).
- Fig. 5. Oxygen consumption of resting (●) polar bear cub, aged approximately 3 months at different ambient temperatures. Values obtained during occasional activity is indicated with open circles (○). The weight of the cub is 12.5 kg.

Fig. 6 Two micrographs of the latissimus dorsi muscle of a polar bear cub aged approximately 3 months. Numerous mitochondria and glycogen granules, but only very few fat droplets are visible.

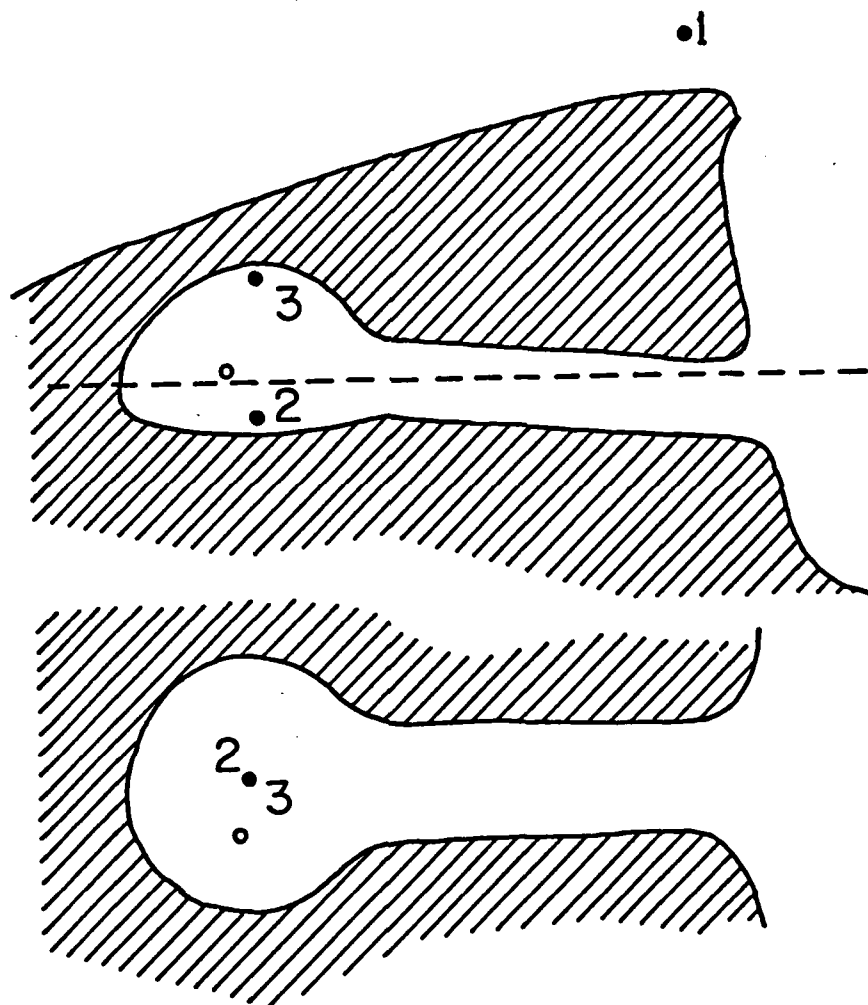


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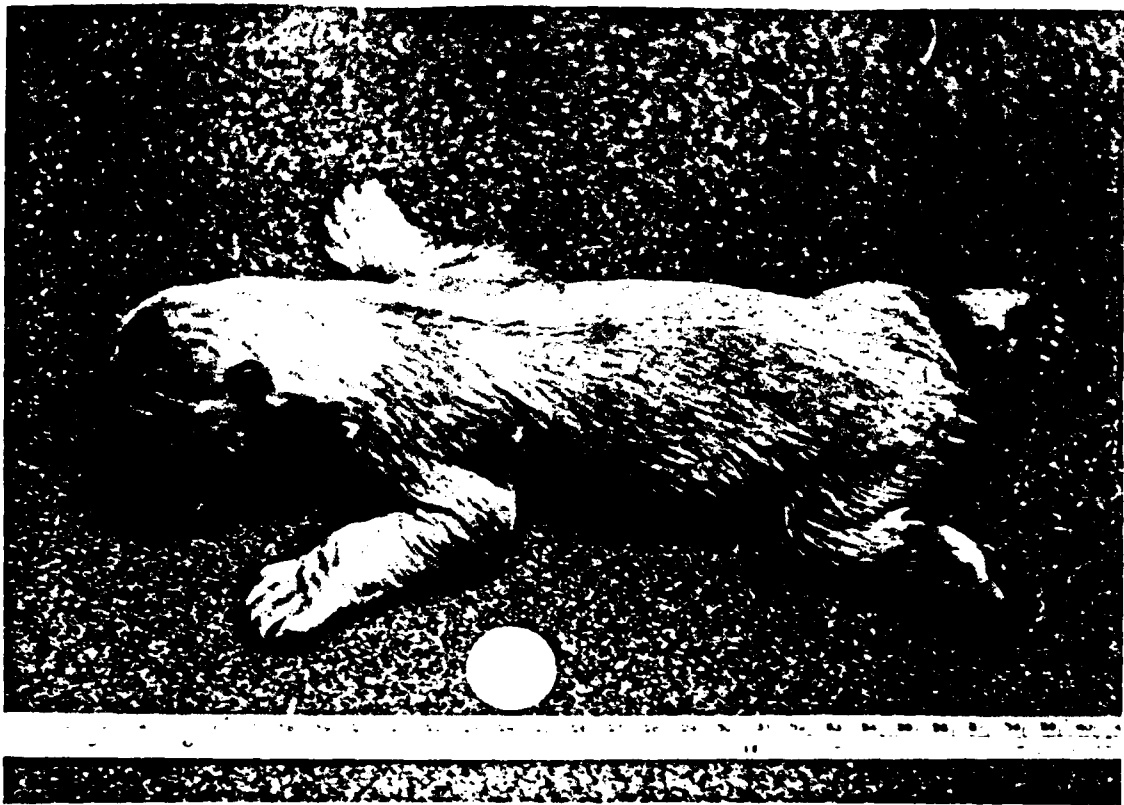


Figure 2

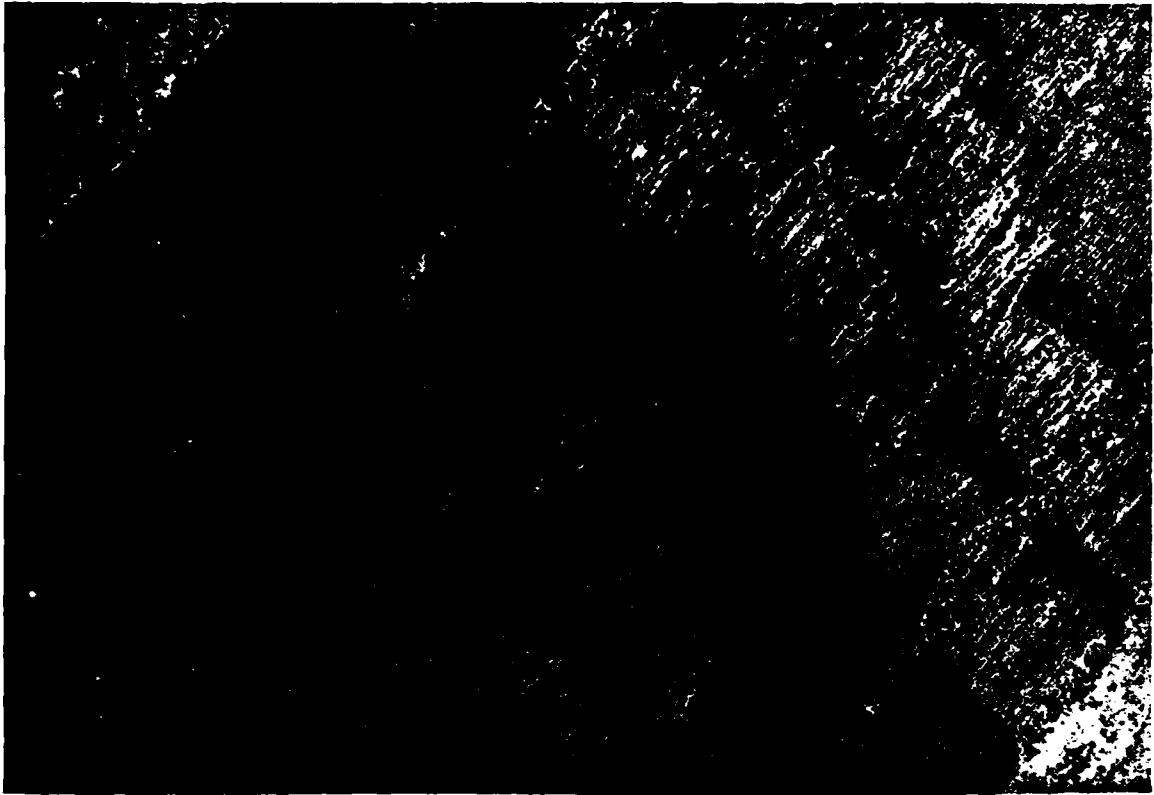


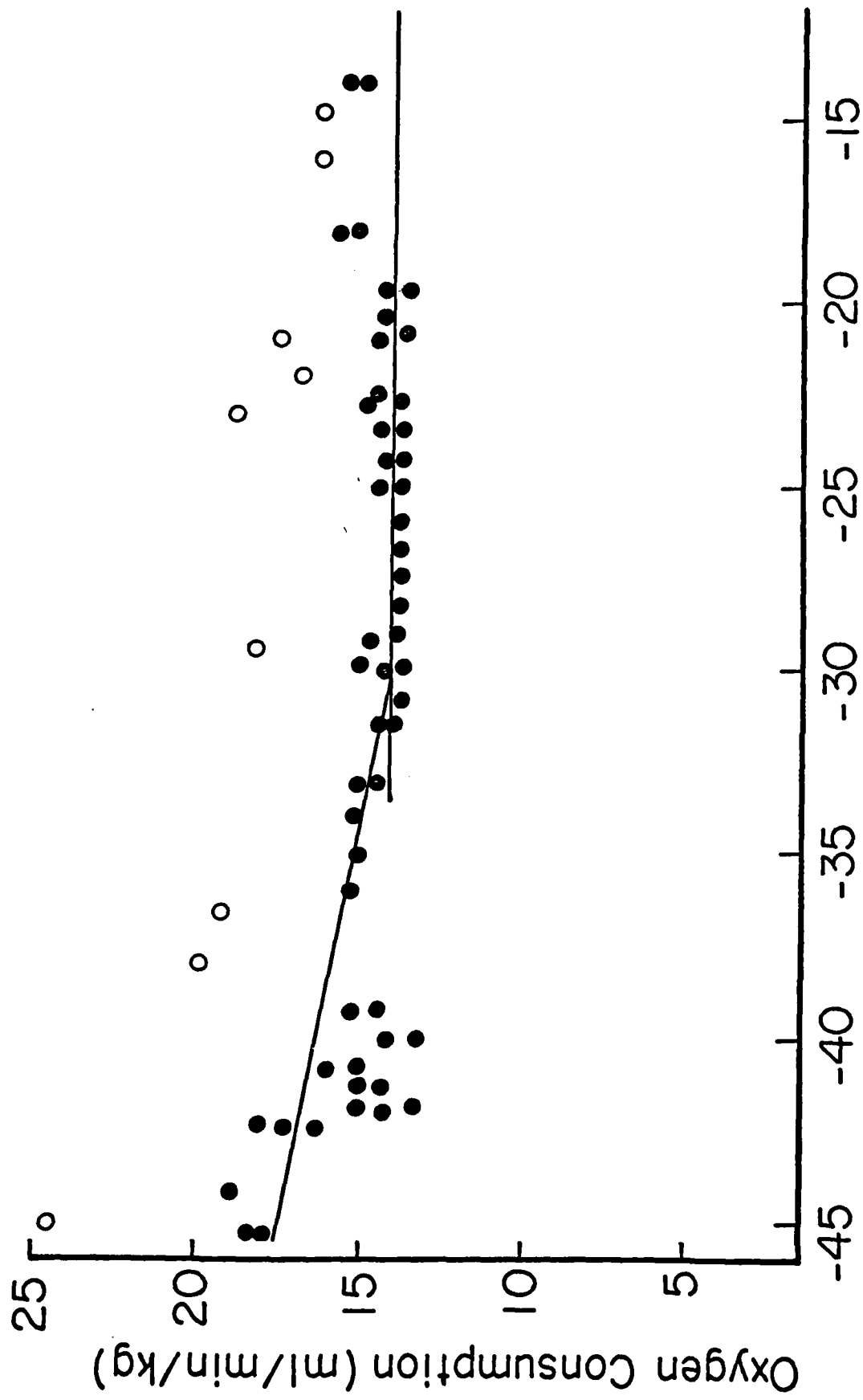
Figure 3A



Figure 3B



Figure 4



Oxygen Consumption (ml/min/kg)

Ambient Temperature (°C)

Figure 5

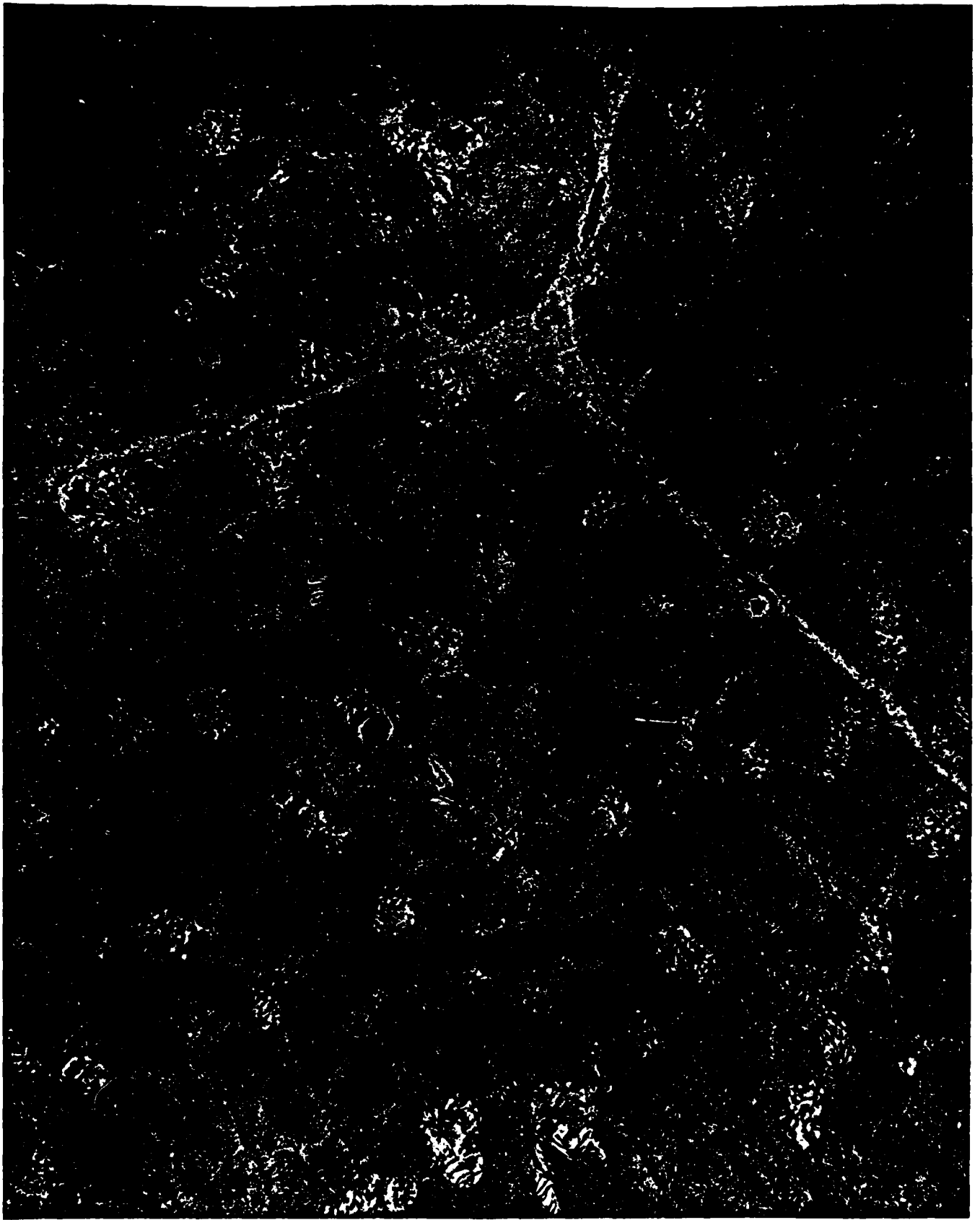


Figure 6A

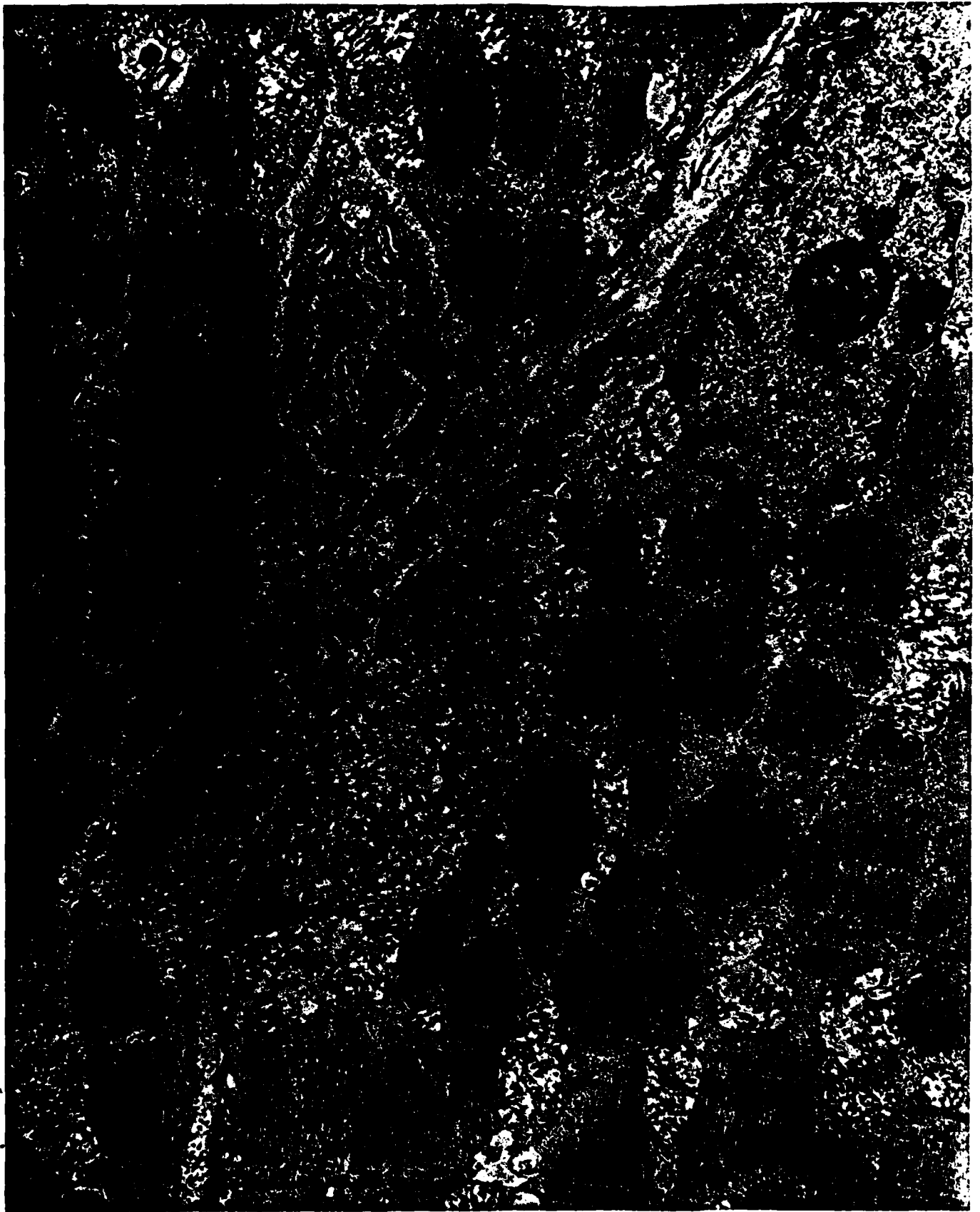


Figure 6B

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