# Short Papers in Geology and Hydrology, Articles 60–119

## GEOLOGICAL SURVEY RESEARCH 1962

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*Scientific notes and summaries of investigations prepared by members of the Geologic and Water Resources Divisions in the fields of geology, hydrology, and allied sciences*

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Thomas B. Nolan, *Director*

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# FOREWORD

This collection of 60 short papers on subjects in the fields of geology, hydrology, and related sciences is the second of a series to be released during the year as chapters of Professional Paper 450. The papers in this chapter report on the scientific and economic results of current work by members of the Geologic and Water Resources Divisions of the United States Geological Survey. Some of the papers announce new discoveries or present observations on problems of limited scope; other papers draw conclusions from more extensive or continuing investigations that in large part will be discussed in greater detail in reports to be published in the future.

Chapter A of this series, to be published later in the year, will present a synopsis of results from a wide range of work done during the present fiscal year.

Thomas B. Nolan

THOMAS B. NOLAN,
*Director.*

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## 65. VARIATION IN RANK OF TERTIARY COALS IN THE COOK INLET BASIN, ALASKA

By F. F. BARNES, Menlo Park, Calif.

Tertiary coals in the Cook Inlet basin of south-central Alaska range in rank from lignite to anthracite. Until recently all the coals sampled had been limited to a relatively narrow stratigraphic range and were at or near the present surface. In 1960 the writer obtained core samples of coals from several wells in the recently developed Kenai oil field from depths of as much as 11,000 feet, and in 1961 he collected samples of lignite from a bed on the Chuitna River, west of Anchorage, that probably is considerably younger than those in other parts of the basin. Proximate analyses (on the as-received basis) and rank of coals from the Kenai wells and of representative samples from other parts of the Cook Inlet basin are given in the table below, and the sampled localities are shown in figure 65.1.

*Analyses of coals on the as-received basis in the Cook Inlet basin, Alaska*

[Analyses by U.S. Bureau of Mines]

| Sample No. | Sampled locality | Rank [1] | Laboratory No. | Moisture (percent) | Volatile matter (percent) | Fixed carbon (percent) | Ash (percent) | Sulfur (percent) | Heating value (Btu) | Moist mineral-matter-free (Btu) |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Kenai field** | | | | | | | | | |
| 1 | Outcrop 14 miles north of Ninilchik. | Lig | D–51010 | 27. 1 | 31. 8 | 25. 4 | 15. 7 | 0. 2 | 6, 640 | 8, 000 |
| 2 | Outcrop 2 miles north of Ninilchik. | Subc | D–49805 | 27. 1 | 36. 5 | 28. 4 | 8. 0 | . 3 | 7, 730 | 8, 460 |
| | Core samples from Kenai oil wells: | | | | | | | | | |
| | *Well* *Depth (feet)* | | | | | | | | | |
| 3 | SRU 14–4 ........ 5, 500 | Subb | G–89425 | 13. 2 | 30. 1 | 24. 6 | 32. 1 | . 8 | 6, 360 | 9, 740 |
| 4 | SRU 34–10 ....... 10, 200 | Hvcb | A–49 | 9. 1 | 38. 1 | 41. 3 | 11. 5 | . 3 | 10, 650 | 12, 150 |
| 5 | SRU 34–10 ....... 10, 230 | Hvcb | G–89428 | 7. 6 | 29. 9 | 37. 4 | 25. 1 | . 3 | 8, 630 | 11, 845 |
| 6 | SRU 32–33 ....... 10, 680 | Hvcb | G–89424 | 7. 7 | 37. 2 | 42. 3 | 12. 8 | . 4 | 11, 190 | 12, 990 |
| 7 | SRU 12–27 ....... 10, 720 | Hvbb | G–89426 | 5. 9 | 38. 7 | 48. 7 | 6. 7 | . 5 | 12, 150 | 13, 100 |
| 8 | SRU 34–16 ....... 11, 110 | Hvbb | G–89429 | 5. 6 | 41. 7 | 45. 7 | 7. 0 | . 3 | 12, 360 | 13, 350 |
| 9 | SRU 34–10 ....... 11, 360 | Hvcb | G–89427 | 4. 9 | 30. 3 | 35. 4 | 29. 4 | . 2 | 8, 800 | 12, 900 |

See footnotes at end of table.

*Analyses of coals on the as-received basis in the Cook Inlet basin, Alaska*—Continued

[Analyses by U.S. Bureau of Mines]

| Sample No. | Sampled locality | Rank [1] | Laboratory No. | Moisture (percent) | Volatile matter (percent) | Fixed carbon (percent) | Ash (percent) | Sulfur (percent) | Heating value (Btu) | Moist mineral-matter-free (Btu) |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Matanuska field** | | | | | | | | | |
| 10 | Houston strip mine, Little Susitna district. | Subb | D–51894 | 20. 3 | 31. 6 | 38. 9 | 9. 2 | 0. 4 | 9, 210 | 10, 250 |
| 11 | Evan Jones mine, Wishbone Hill district. | Hvbb | A–98201 | 5. 2 | 34. 7 | 41. 4 | 18. 7 | . 4 | 10, 860 | 13, 620 |
| 12 | Chickaloon mine, Chickaloon district. | Lvb | 85740 | 1. 3 | 16. 2 | 66. 4 | 16. 1 | . 6 | 12, 690 | [2] 81. 8 |
| 13 | Outcrop, Anthracite Ridge district. | An | 12746 | 2. 9 | 7. 8 | 77. 3 | 12. 0 | . 6 | 12, 730 | [2] 92. 7 |
| | **Susitna field** | | | | | | | | | |
| 14 | Outcrop on Chuitna River, Beluga district. | Lig | H–17384 | 33. 1 | 32. 9 | 27. 6 | 6. 4 | 0. 1 | 7, 260 | 7, 800 |

[1] In accordance with American Society for Testing Materials (1939). Ranks were determined from calculated moist mineral-matter-free Btu or dry mineral-matter-free fixed carbon.

[2] Calculated dry mineral-matter-free fixed carbon, in percent.

Several factors have been considered by different writers to be primarily responsible for increasing the rank of coals (Hendricks, 1945, p. 14–19). Chief among these are: (a) length of time since burial of vegetation, (b) depth of burial (load metamorphism), (c) heat from compression by or from intrusion of igneous rocks (thermal metamorphism), and (d) pressure from horizontal stress (regional metamorphism).

The coals in outcrops in the Kenai field are lowest in rank and those in the core samples from this field show a general increase in rank with depth (fig. 65.2). As available data indicate that all these coals originated during one general period of continental deposition, it seems unlikely that difference in age alone could account for the difference in rank. The enclosing Kenai Formation has not been intruded by

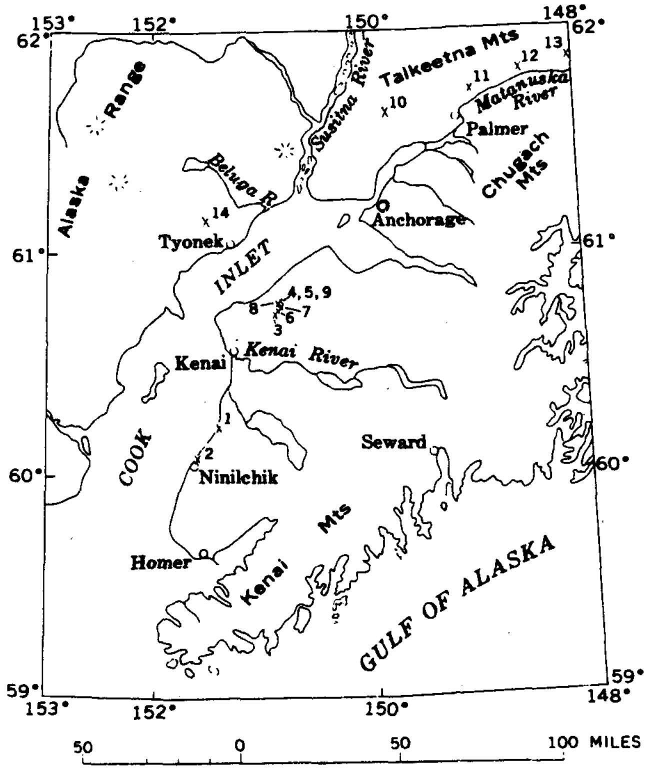

FIGURE 65.1.—Index map of Cook Inlet basin, showing sampled coal localities listed in table.

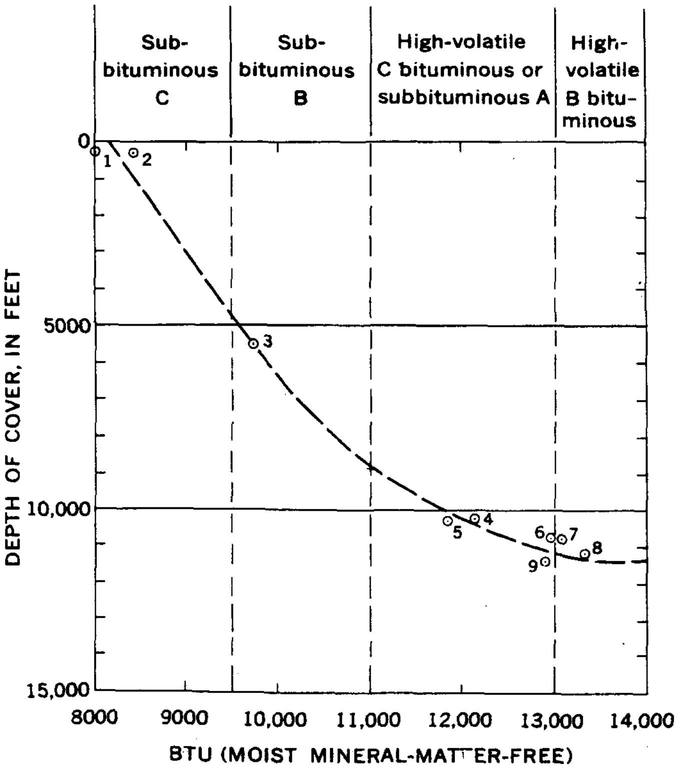

FIGURE 65.2.—Relation of rank to present depth of cover of Kenai coals. See table and figure 65.1 for localities sampled.

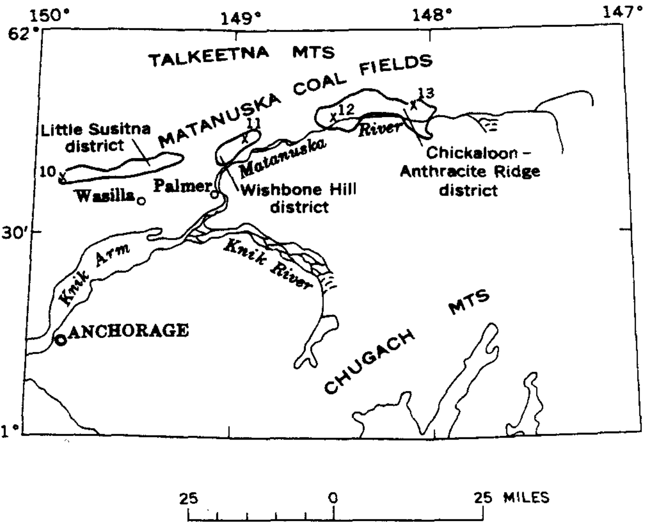

FIGURE 65.3.—Index map of Anchorage quadrangle, showing sampled coal localities in the Matanuska coal field.

igneous rocks and has undergone only mild folding and normal faulting, so that both thermal and regional metamorphism probably can be safely ruled out as dominant factors in increasing the rank of the coals. It therefore seems probable that load metamorphism was chiefly responsible for increasing the rank of the deeper Kenai coals.

In the Matanuska coal field, at the head of Cook Inlet north of Anchorage, coals of the Chickaloon Formation, of early Tertiary age, increase progressively in rank from subbituminous at the west end of the field, through high-volatile bituminous in the central part, to low-volatile bituminous and anthracite at the east end of the field (see fig. 65.3 and table). Although the coals in the different parts of the field have not been closely correlated, available evidence indicates that they are all part of the same general sequence and hence do not differ greatly in geologic age. Also, no evidence is known to indicate that the coals of the eastern end of the field were more deeply buried than those to the west. The degree of deformation changes markedly, however, from slight folding and faulting in the western part of the field (Barnes and Sokol, 1959, p. 125–126) to extremely complex folding and faulting in the eastern part (Capps, 1927, p. 51–55). Furthermore, intrusive dikes, sills, and stocks are abundant in the eastern part of the field, of minor occurrence in the central part, and totally lacking in the western part. These relations strongly suggest that the dominant factors in increasing the rank of the coals were heat and pressure resulting from regional deformation accompanied by igneous intrusion.

In 1961 the writer sampled a 30-foot coal bed on the Chuitna River in the Susitna field west of Anchorage; analysis has shown this coal to be considerably lower in rank than typical Kenai coal (see table). The enclosing rocks are similar to those of the Kenai field and, like them, have undergone only slight deformation and are free of intrusive rocks. However, they contain fossil leaves that, according to Jack A. Wolfe (written communication, 1962), may be considerably younger than the typical Kenai flora and are of probable early or middle Miocene age. This coincidence of lower rank with probable younger age suggests that length of time since burial is the dominant factor affecting the rank of the Chuitna River coal.

In summary, evidence indicates that several factors have played a part in advancing the rank of Tertiary coals in the Cook Inlet basin, and that no single factor was universally dominant. The following conclusions appear to be warranted:

1. Age and a moderate depth of burial have been sufficient to advance to subbituminous rank all coals deposited in early Tertiary time. Relatively undisturbed coals of probable middle Tertiary age have not passed beyond the lignite stage.
2. Load metamorphism has raised to bituminous rank the deeper coals in the Kenai field, but so far as is known it had little effect on coals in other parts of the basin. Deep drilling may reveal higher rank coals at depth in other areas, for example in the western part of the Matanuska field.
3. Regional metamorphism resulting from horizontal stresses, possibly aided by heat from igneous intrusions, has raised coals to bituminous and higher ranks in the Matanuska field but has not been an important factor elsewhere in the Cook Inlet basin.

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## *GLACIOLOGY AND GLACIAL GEOLOGY*

### 94. GRAVIMETRIC DETERMINATIONS OF ICE THICKNESS OF JARVIS GLACIER, ALASKA

By NED A. OSTENSO and G. WILLIAM HOLMES, University of Wisconsin, Madison, Wis., and Washington, D.C.

Jarvis Glacier, in central Alaska (fig. 94.1), is about 5 miles long and ½ mile wide and lies in a deep U-shaped valley on the north flank of the Alaska Range. Surface elevations range from about 4,000 feet at the snout of the glacier to 6,000 feet in the cirque. The glacier is well suited to glaciological study because of its small size and relatively smooth surface. It is accessible by trail along Jarvis Creek, and by light aircraft, which can land almost anywhere on the glacier.

In conjunction with other glaciological studies, 76 gravity stations were established on the glacier during the period March 30 to May 1, 1955. Ice thickness was determined by the difference in the density of the glacial ice and the underlying rock. Although ice-thickness determinations made by gravimetric observations are less accurate than those made by seismic measurements or by borings, the method has the advantage of speed and ease of operation, and requires a minimum of equipment and logistics support. Moreover, crevasses, basal roughness, or extreme slopes, common in mountain glaciers, frequently preclude the use of seismic soundings.

These studies were conducted as a private project by Ostenso in cooperation with general investigations in the area by Holmes that were sponsored by the U.S. Army Corps of Engineers Waterways Experiment Station. The work was generously supported by Prof. G. P. Woollard, University of Wisconsin, who supplied the gravimeter. Major James R. Evans, U.S. Air Force, flew the aircraft and provided valuable field assistance. Daniel Sokol, of the U.S. Geological Survey, assisted in the fieldwork.

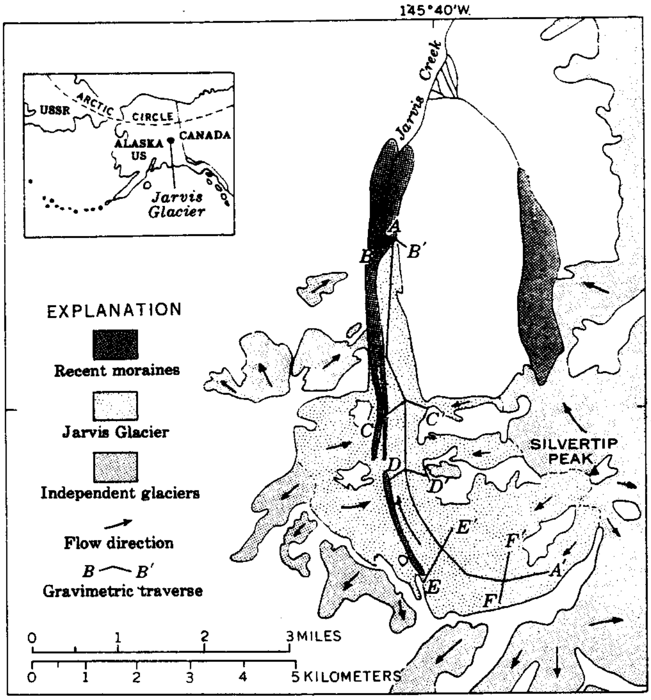

FIGURE 94.1.—Map of Jarvis Glacier, Alaska Range, showing principal features, direction of flow, and location of gravity traverses.

This part of the Alaska Range is composed of the early Precambrian Birch Creek Schist series, a complex unit of metasedimentary rocks including quartzite, quartzite schist, sericite schist, and gneiss (Wahrhaftig and Hickcox, 1955, p. 354; Capps, 1940, p. 97).

Jarvis Glacier is nourished chiefly by firn fields on the flanks of the mountain locally known as Silvertip Peak and on the cirque wall to the south. Three small hanging glaciers on the west wall of the valley may have nourished the glacier during recent glacial advances. Like many other glaciers in the area, Jarvis Glacier has recently retreated and decreased in volume. The firn limit is normally high in the cirque; in 1955 it was at an elevation of approximately 5,700 feet. Well-developed lateral moraines with relief of 20 to 30 feet lie along most of the lower two-thirds of the glacier. The outer moraine is slightly weathered, and the inner moraine is fresh. Both lateral moraines converge into a poorly defined end moraine, which has been partly breached by melt water. This pattern of two moraines, considerably smaller and younger than the massive late Pleistocene Donnelly moraines to the west in the Delta River valley, is typical of glaciers in this section of the Alaska Range.

A Worden geodetic gravimeter (No. W14), calibrated against the Gulf-Wisconsin pendulum station network, was used because of its light weight, ruggedness, and independence of external power source.

Five gravity traverses were made across Jarvis Glacier and one the length of the glacier (fig. 94.1). The location of the stations was determined by triangulation on mountain peaks using a telescopic alidade; the distance between individual stations was chained. All elevations were determined with the alidade; their relative accuracy is estimated to be within 2 feet. The entire survey network was reduced to sea level by multiple ties to a U.S. Coast and Geodetic Survey benchmark by altimeter, with a probable accuracy of ±10 feet.

The gravity method for determining ice thickness assumes that variations in the Bouguer anomaly over the glacier surface are primarily a function of the thickness of the underlying ice. If the difference in the density of the ice and the country rock is known, the ice thickness may be estimated by considering it proportional to the Bouguer anomaly. In practice, however, this correlation is complicated by the fact that the gravimeter measures the strength of a potential field, and readings are influenced by a large mass of glacier ice rather than the small column of ice directly beneath it. This results in an "averaging" effect which is a function of the irregularity of the ice–rock interface, the ice thickness, the proximity to valley walls, and the density differential between ice and rock. Variation in the density of the ice and the rock also complicates the relationship, but the contrast is large and a density change of 0.1 gm per $cm^3$ for either rock or ice will cause an error in ice thickness of less than 3 feet per milligal. Isostatic effects and variation in bedrock density may also cause gravity anomalies which might be interpreted as changes in ice thickness. However, the gravitational effect of these deeper, bedrock variations can usually be eliminated by measurements along the margin of the glacier. In general the gravity method for determining ice thickness is rapid and reasonably accurate.

Theoretical sea-level gravity was obtained from tables based upon the International Gravity Formula. The simple Bouguer correction was applied to the free-air gravity by assuming a density of 2.67 gm per $cm^3$ for the country rock, primarily schist and quartzite. As Jarvis Glacier is situated in a deep mountain valley, terrain corrections had to be applied to all reductions of observed gravity. These corrections were determined by the zone chart and tables computed by Hammer (1939). The magnitude of these corrections varied from 1.34 mgal (milligal) for a central station to 5.87 mgal for a station at the edge of the glacier.

The corrected observed gravity was subtracted from the theoretical gravity for each station to give the

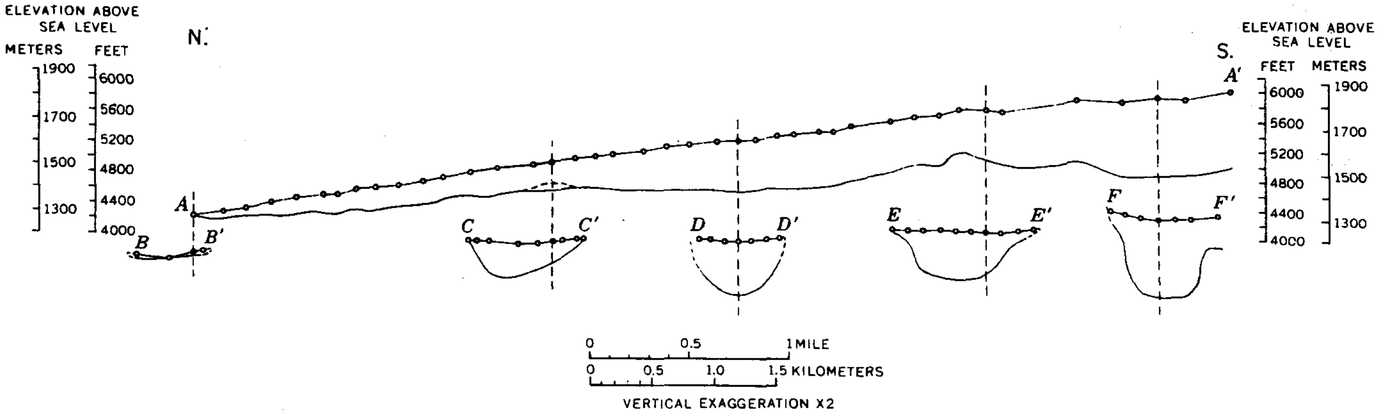

FIGURE 94.2.—Profiles of the Jarvis Glacier, Alaska Range, Alaska. Gravimetric stations are shown by dots; location of traverses is shown on figure 94.1.

Bouguer anomaly. The Bouguer anomalies showed an inverse correlation with elevation because of the effect of isostatic compensation and geologic structure. In order to compensate for this regional gradient, the traverses extended beyond the edge of the glacier wherever possible, and interpolations for the intermediate points were made where crevassing prevented extending the profiles to bedrock. The observed gravity at the stations on bedrock were set equal to the theoretical gravity at these points, and appropriate regional corrections were applied to all of the stations on the glacier. These stations then showed residual Bouguer anomalies which were a function of the deficiency in mass of the ice column between the instrument and the underlying rock.

For convenience in calculating ice thickness from the residual Bouguer anomalies, a simple geometric model was constructed with the glacier represented as an infinite slab. The total gravitational effect, $g$, at any point over such a slab can then be represented as: $g=2\pi\gamma\rho t$ mg, where $\gamma$ is the gravitational constant, $6.67\times10^{-8}$ cgs units; $\rho$ is the density differential between the ice and the rock; and $t$ is the ice thickness, in centimeters. Assuming a density of 0.89 g per cm$^3$ for the glacial ice and 2.67 g per cm$^3$ for the country rock, $\rho$ would equal 1.78 g per cm$^3$, and a Bouguer anomaly of 1.0 mgal would be equivalent to 44 feet of ice. After the approximate ice thickness was calculated, a refined determination of the glacier profile was obtained by using a line integral method described by Hubbert (1948).

The results of the gravity traverses on Jarvis Glacier are shown as profiles in figure 94.2. Unfortunately, part of the fieldwork was conducted during a period of poor visibility, and the longitudinal traverse deviated from the central axis of the glacier, resulting in an apparent thinning of the ice (dashed on profile *A–A'*). This discrepancy was adjusted by substituting the greatest ice thickness along transverse profile *C–C'* where it crossed the point of deviation. The presence of crevasses made it impossible to extend some traverses beyond the glacier.

The valley of Jarvis Glacier has a pronounced U-shaped transverse profile and a relatively smooth bottom. A maximum ice thickness of 1,055 ft was found in the center of the cirque. Transverse profile *F–F'* (fig. 94.2) through the cirque shows a small tributary glacier joining it from the southwest slope of Silvertip Peak. Of particular interest is the sill on the down-glacier end of the cirque (west of profile *E–E'*, fig. 94.2). Ice must flow uphill in moving from the cirque into the glacial valley. The overdeepened cirque can be explained by erosional mechanisms such as rotational slip (Lewis, 1949) or perhaps by increased erosion under conditions of compressive flow (Nye, 1952), or by a combination of the two. The longitudinal profile in figure 94.2 shows that the glacier is at present too thin and without sufficient surface slope for rotational slip to occur and cause abnormal cirque scouring. During earlier advances, however, the glacier originated higher in the cirque and rotational slip may have occurred. Once the sill started to form, the process could be continued according to the theory of Nye (1952) and Sheidegger (1961). The cirque floor would have a concave profile over which glacial flow would be compressive and erosion would be intensified.

The abrupt change in surface slope over the cirque sill is in qualitative agreement with Nye's hypothesis (1959) which states that the surface slope is inversely proportional to the ice thickness. Paucity of data along this critical portion of the profile, the lack of precision of subice topographic measurements by the gravity method, and the effect of side friction preclude a quantitative testing of Nye's general law.

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