Structure of the Survey Pass quadrangle, Brooks Range, Alaska

By

Donald Grybeck and Steven W. Nelson

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INTRODUCTION

The structure of the Survey Pass quadrangle is complex and subject to considerable uncertainty. This structural interpretation is based on more than 2,900 structural measurements synthesized on the accompanying map, structural relations noted during fieldwork, and structural relations noted by previous workers in the Survey Pass quadrangle and adjacent areas. The map is one of a series making up a folio that provides an estimate of the mineral resources of the quadrangle under the Alaska Mineral Resource Assessment Program (AMRAP). The work of this and other reports of the folio, all in the MF-1176 map series of the U.S. Geological Survey, is described in the U.S. Geological Survey Circular 835. The structure map and report rely greatly on another part of the Survey Pass folio, the geologic map (Nelson and Grybeck, 1980), for structural data, field relations, references to radiometric dates, and the map explanation, which are used here without citation.

GENERAL GEOLOGY

Most of the rocks in the Survey Pass quadrangle can be confidently dated as Devonian even though the fossil evidence is sparse in the southern part of the quadrangle. Mississippian rocks crop out discontinuously in the central and northern parts of the quadrangle and the widespread Skajit Limestone has been considered to include Silurian as well as Devonian rocks elsewhere in the Brooks Range (Brosgé and Dutro, 1973).

The age of the schist belt, a low-grade schist in the southern part of the quadrangle (fig. 1), is ambiguous; radiometric dates and fossil evidence indicate ages from Precambrian to Triassic. Turner and others (1978) have dated glaucophane schists to the west in the Ambler River as Precambrian(?) by potassium-argon methods; lithologically similar schists occur widely in the schist belt of the Survey Pass quadrangle. On the basis of fossil evidence, Smith and others (1978) suggest a Devonian or Early Mississippian age for a marble unit from the schist belt. Their lead-isotope data indicate a middle Paleozoic age for the volcanogenic copper-zinc deposits that occur in the schist belt. M. L. Silberman (Nelson and Grybeck, 1980) has indicated a possible Triassic age for the metafelsite in the schist belt (T. 19 N., R. 17 and 18 E.) on the basis of a preliminary whole-rock rubidium-strontium isochron. Further confusing the picture are uranium-lead dates on zircon that yield a Precambrian age for an isolated body of biotite-feldspar-quartz schist and gneiss near Ernie Lake in T. 24 N., R. 26 E., just east of the Survey Pass quadrangle and north of the schist belt, but perhaps related to it (Dillon and others, 1980). More generally, Precambrian or lower Paleozoic rocks are widespread in the Brooks Range (Grybeck and others, 1977), and correlative rocks may occur in the schist belt or the central part of the quadrangle. Numerous samples of rocks from within the schist belt give Cretaceous potassium-argon dates (Turner and others, 1978), but these dates represent a post-depositional metamorphic event. In summary, the age of the metamorphic rocks in the schist belt is uncertain; some are Devonian or Early Mississippian; most may be Devonian, some may be as old as Precambrian or as young as Triassic.

The metamorphic rocks north of the schist belt in the central and in particular the west-central part of the quadrangle are of uncertain age; the few fossil ages and radiometric dates are ambiguous and correlation with rocks north and east is based only on gross lithologic similarity.

The metamorphic rocks in the south half of the quadrangle commonly show evidence of polymetamorphism in many places; as many as three metamorphic fabrics can be identified in outcrop. The time of the metamorphic events is unclear partly because the time of the deposition of many of the rocks is unknown. Precambrian, Devonian, and Cretaceous metamorphic events have been proposed. The rationale for Precambrian metamorphism rests on the potassium-argon dates mentioned in connection with the age of the schist belt. That correlation is refuted by Smith and others (1978) who state that the so-called Precambrian rocks were deposited in Devonian or Early Mississippian time and could hardly have undergone a Precambrian metamorphic event. Devonian metamorphism is indicated by field relations. The largely Devonian rocks that form at least part, and possibly most, of the country rock adjacent to the Devonian granites appear to have had a metamorphic fabric prior to intrusion. The main problem with a pre-granite metamorphism is that it requires deposition of a wide variety of marine sediments followed by (regional?) metamorphism and then intrusion, all in Devonian time. The concept of Cretaceous metamorphism is, in part, an artifact of the long-supposed Cretaceous age of the granites, an age assignment based (perhaps with reservations) on potassium-argon dates that has been used by most of those geologists who have worked with the granites before 1977. Despite the possible misjudgment of the age of the granites, numerous potassium-argon dates obtained from both the granites and metamorphic rocks (Turner and others, 1978) substantiate a Cretaceous metamorphic event that may have produced a penetrative metamorphic fabric throughout the quadrangle.

Although the rocks in the quadrangle are commonly described in the terminology of sedimentary rocks, most are metamorphic rocks. The Hunt Fork Shale, for example, is a phyllite in the quadrangle, and the Skajit Limestone is almost everywhere a marble. The metamorphic rocks reach medium grade (following Winkler, 1976) in the central and southern part of the quadrangle (Nelson and Grybeck, 1981). Most of the rest of the southern two-thirds of the quadrangle is largely formed of low-grade metamorphic rocks characterized by muscovite, albite, and chlorotoid with local occurrence of retrograde glaucophane in the schist belt. Evidence of transposition of the sedimentary layering abounds. Scattered occurrences of Mississippian quartz conglomerate, probably correlative with the Kekiktuk Conglomerate, are characterized by ubiquitous detrital(?) kyanite in sparse grains less than 1 mm in size. In the northern third of the quadrangle, sandstones and quartzites in units such as the sandstone of the Hunt Fork Shale and the Kanayut Conglomerate retain their sedimentary textures and mineralogy. But the finer grained deposits, the Hunt Fork Shale, for example, have a penetrative metamorphic cleavage or phyllitic layering oblique to the sedimentary layering.

The Devonian granitic orthogneiss that forms two large plutons in the center of the quadrangle is almost everywhere foliated. In several localities two foliations can be identified. Locally in the granite, folds range from centimeters to hundreds of meters in amplitude. The foliation ranges from schistocity in fine-grained granites to cataclastic gneissic layering with development of augen in coarse-grained varieties. However, weakly foliated, fine- to coarse-grained granite with trachytoid layering is common. The foliation in the granite is rarely coincident with that in adjacent metamorphic rocks, and, as will be shown, the stereonet plots of the granitic foliation indicate that it is oblique to the regional foliation. Our reconnaissance work does not allow a clear definition of the complex textural and structural variations within the granite. The high rugged topography of Arrigetch Peaks and Mount Igikpak is related to coarse-grained granite or orthogneiss, whereas the more rounded topography that characterizes areas such as the northeast lobe of the Mount Igikpak pluton is typically formed on a fine- to medium-grained schistose granite. At many places, grain size and texture vary gradationally within meters, and coarse-grained orthogneiss occurs within
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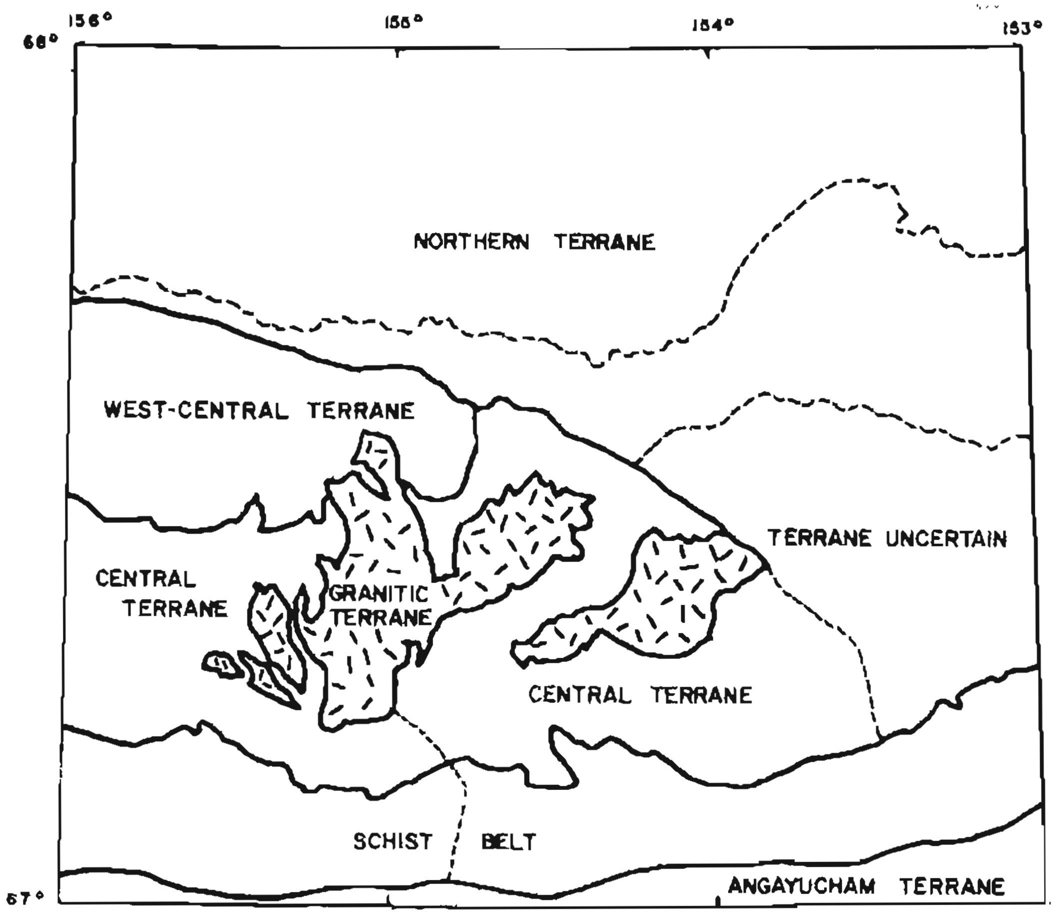

Figure 1.--Structural terranes of the Survey Pass quadrangle, Alaska. Dashed lines are boundaries of domains as used in this report.

of the contact of the plutons. The age of the foliation in the granite is not clear. We suggest that foliation developed just after intrusion in Devonian time while the cooling bodies were still subject to the stresses of the orogeny that generated the granitic magma. This interpretation is based on the Devonian orogeny, which appears to offer the only time when the pluton was subject to localized, elevated temperature and also to stresses sufficient to produce complex foliation. Later deformation probably would not have produced a foliation unique to the granite. A Cretaceous age for the foliation cannot be entirely precluded because Cretaceous potassium-argon dates in the granite unmistakably mark a thermal event and possibly a metamorphic event sufficient to form the foliation.

The granites are surrounded by a wide band of medium-grade metamorphic rocks, and the immediate contact is marked by numerous discontinuous calcareous skarn bodies too small to map at 1:250,000 scale. These contact-metamorphosed rocks and the sharpness of the contacts substantiate an intrusive origin for the granites. The northern contacts of both Mount Igipak and Arrigetch Peaks plutons dip gently to the north, and the northeast lobe of the Mount Igikpak pluton forms a northeast-trending dome under shallow-dipping metamorphic rocks. The southern contacts of the plutons are generally steep where defined; at some places they are obscure. The contact of the Arrigetch Peaks pluton north of Walker Lake in T. 22 N., R. 20 E. is a thrust fault that dips north at about 25° isolating two granite klippen. Aeromagnetic (Cady and Hackett, 1981) and geologic evidence suggests that the Mount Igikpak and Arrigetch Peaks plutons merge at depth as part of a larger east-trending pluton that extends under much of the central part of the quadrangle.

One of the major uncertainties of the geology of the quadrangle is the stratigraphic relation between widely different Devonian assemblages of rocks in proximity to each other. For example, the Upper Devonian assemblage in the northern third of the quadrangle is represented by several thick clastic units that include the upper sandstone of the Hunt Fork Shale and the Kanayut Conglomerate. These units are entirely missing in the central part of the quadrangle between the Silurian and Devonian Skajit Limestone and the Mississippian rocks.

Two opposing concepts can be used to explain the relations; one is stratigraphic, the other structural. The stratigraphic interpretation accounts for the Devonian succession by repeated migration of basinal environments across the area in response to vertical movements. Many interpretations of the geology of the Brooks Range have been built largely upon the concept of basinal migration and lithologic pinchouts; see as a recent example, Brosgé and Dutro (1973). The fossil evidence supports stratigraphic superposition of Devonian strata in the core of the Brooks Range in many areas. For example, stratigraphic superposition of the Upper Devonian rocks of the north half of the Survey Pass quadrangle is well documented by Dutro, Brosgé, and Reiser (1977).

The structural interpretation suggests that the Brooks Range has been subject to hundreds of kilometers of thrust faulting, largely of Cretaceous age, that has telescoped the stratigraphic succession, in many places juxtaposing coeval lithofacies (Tailleur and Brosgé, 1970; Newman and others, 1979; Roeder and Mull, 1978). Boucher (1978) and Tailleur (1973), among other workers, have related the thrust faulting to counterclockwise rotation of northern Alaska from the Arctic archipelago. Our work does not resolve the disparity in interpretation largely because fossils are sparse in the central and southern parts of the quadrangle. We are, however, impressed with the magnitude of thrust faulting in the area and suggest that the present geologic structure is the product of both shifting Devonian depositional environments and subsequent Mesozoic thrust faulting of great magnitude.

GENERAL STRUCTURE

The structure of the Survey Pass quadrangle is dominated by numerous thrust faults of unknown but probably major displacement; some of these faults are folded. The absence of post-Mississippian rocks over most of the quadrangle precludes any closer age determination for the thrust faults than post-Devonian or post-Mississippian. However, tectonic syntheses of the geology of the Brooks Range indicate that most of the thrust faults are Neocomian to Aptian age (Tailleur and Brosgé, 1970; Newman and others, 1979; Roeder and Mull, 1978). Almost all of the numerous thrust faults shown on the geologic map are inferred. Rarely were fault features seen in the field unequivocally thrust faults; the many units of ambiguous age and the absence of detailed stratigraphy, as well as the possibilities for metamorphic transposition, made identification of thrust faulting difficult at any given location. Generally, however, the thrust faulting can be confidently inferred from truncation of units, divergency of structure on opposite sides of faults, and stratigraphic breaks or reversals evident even in areas where the stratigraphy is uncertain. It is likely that with more detailed mapping, more major thrust faults could be identified.

Major high-angle faults are not common, although several prominent high-angle faults cut the Devonian granite. An arcuate, high-angle fault truncates the northeast side of the Arrigetch Peaks pluton, and even more striking faults cut the granite north-northwest of Walker Lake (T. 22 and 23 N., R. 19 E.) and in the upper Reed River area (T. 22 and 23 N., R. 17 E.). The fault zones in the Walker Lake and Reed River areas are marked by prominent "dikes", about 10 m wide, of a silicified coarse-grained aggregate of subhedral feldspar crystals probably formed by alteration rather than intrusion.

The rocks within the quadrangle are commonly folded, but the style of folding is not consistent. Many folds are apparently simple, but complex refolding is common in the southern two-thirds of the quadrangle. Folds are both open and closed, chevron, symmetrical and asymmetrical, parallel and similar, and a few are ptygmatic. The most common types are isoclinal folds, commonly recumbent and ranging in size from microscopic to hundreds of meters in amplitude, and, in the schistose and phyllitic rocks, small-scale shear or slip folds. The vergence of the folds (here defined as the bearing of the perpendicular to the strike of the axial plane measured toward the anticlinal hinge) is inconsistent; in the central part of the quadrangle most verge toward the south (Mull, 1977). East-west fold axes predominate, but the dip of the axial planes varies greatly. Regional-scale nappes cannot be substantiated but may be present; many small recumbent isoclinal folds mimic nappes, although most are symmetrical with equally developed limbs. The large synclinal folds in the north-central part of the quadrangle (T. 25 N., R. 18 and 19 E.) involving Mississippian to Triassic rocks may represent the general fold style in the northern third of the quadrangle. If large folds are present in the Hunt Fork Shale, its upper sandstone member, or the Kanayut Conglomerate, they are masked by the homogeneity of these units.

The so-called Walker Lake lineament or fault that forms the northern boundary of the schist belt has long been controversial. Its origin has been explained variously as a surface expression of a change in lithofacies (Smith and others, 1978), a folded unconformity (Wiltse, 1975), a metamorphic isograd (Forbes and others, 1974), and a (folded) thrust fault (Fritts and others, 1972; Patton and others, 1973). Its origin is obscure because there is no continuous clearly defined break at the supposed fault, because the metamorphic rocks to the north and south of it generally dip shallowly northward at about the same attitude in the Survey Pass quadrangle, and because the supposed Devonian age of the rocks north of it is based only on gross lithologic correlation. The Walker Lake lineament is a major discontinuity between rocks of different metamorphic grade as well as a lithologic break between terranes that are dominated by schists and carbonates, respectively, and, as will be shown, is a discontinuity between rocks of different structural style. Our conclusion is that the Walker Lake lineament is probably a folded unconformity or a folded thrust fault that has been subject to at least one metamorphic event.

STRUCTURAL DOMAINS

The structural data obtained in this work were analyzed by separating the measurements by structural domains as represented on the accompanying map. These domains were initially established mainly on geologic criteria, that is, by setting the boundaries to encompass geologic units or associations of similar rocks with apparently similar structures. In several areas, for example, domains VIII and IX which together make up the schist belt, geologic units are subdivided along arbitrary geographic boundaries to test the homogeneity of the structural data within these units. It should be noted, however, that although more than 2,900 structural measurements are synthesized on the accompanying map, the average is only about one measurement per 5 km^2. Thus, the stereonet plots delineate only regional patterns; the complexity of structures seen along detailed traverses indicates that locally the structural fabric may differ markedly from the regional patterns.

As seen in the field, definition of planar and linear structures in the rocks is at many places obscure, particularly between bedding, schistocity, and cleavage. The different types of planar and linear structures plotted separately on preliminary compilations almost invariably produced similar patterns in a given domain. The S and L stereonet data are aggregated to reduce an unwieldy number of similar diagrams and to amass on any one diagram data sufficient to contour with confidence. Many of the outcrops provide clear evidence of multiple deformation, each with its separate structural orientation. These deformations were distinguished in the field notes, where possible with the order of development of the various structural elements. However, the planar and linear structures of different age are aggregated because of the absence of area-wide criteria by which to assign particular structural elements at a given exposure to the overall history of structural deformation. The relative simplicity and consistency of the aggregated data argue that aggregation, though masking local complexity, is useful in defining the major structural elements of the quadrangle.

Domain I

Domain I is a domain mainly of monotonous black Devonian phyllite, quartz sandstone, and feldspathic sandstone of the Kanayut Conglomerate and the Hunt Fork Shale. Few obvious folds occur, but numerous large, similar, open to chevron folds at various orientations can be seen from a favorable position if the lighting is right. Several areas contain younger rocks, notably Mississippian through Triassic rocks exposed in the syncline in the central part of the domain.

The stereonet plots indicate a simple regional structure that consists of a cylindrical fold system with flat axes oriented about S. 85° E. and fanned or divergent axial planes that strike parallel to the trend of the folds. The lineation plot is suggestive of a flat large-circle girdle. It possibly represents an earlier deformation, most likely a weaker one whose lineation now lies in the plane of the dominant flat S-surfaces.

Domain II

Domain II is mainly a heterogeneous, unnamed Devonian sequence of calcareous phyllite and black shale to phyllite with subordinate quartz conglomerate, limestone, and schist. The rocks generally are flat lying. Large folds are absent; small-scale folds of diverse style can be seen on many outcrops. The structure may be more complex than is readily apparent, for much of the topography is subdued and covered by tundra; marker horizons are few and commonly of limited extent. The limited continuity of the marker horizons suggests structural complexity.

The stereonet plots, much the same in pattern and simplicity as domain I, indicate that the dominant structures are simple east-west folds with flat-lying limbs. The axes that coincide with the lineations are flat and oriented east-west; the axial planes are fanned or divergent with an east-west strike. The flat large-circle girdle developed by the lineations noted is similar to the plot of domain I, but is even more distinct. This girdle cannot be easily explained by a simple east-west fold system.

Domain III

Domain III is primarily the Skajit Limestone and associated orange-weathering carbonates with a band of Hunt Fork Shale and kyanite-bearing Mississippian(?) conglomerate north of the carbonates. The carbonates, mostly marbles, commonly are highly deformed, at many places rheomorphically; preservation of bedding is rare. Clearly defined large folds are few. However, a striking recumbent isoclinal fold, apparently south vergent, is seen in the limestone cliff face (T. 23 N., R. 24 E.) northeast of Takahula Lake.

The stereonet plots do not yield a simple unambiguous explanation of the structure. Both the foliations and axial planes dip shallowly to the north with a suggestion of a large-circle north-south girdle in the foliation. The consistent foliation, together with the parallel axial plane orientation, suggests recumbent isoclinal folds, possibly with an east-west orientation. The lineations plot as a prominent, flat large-circle girdle that tends to suggest a concentration of roughly east-west lineations, possibly related to an east-west fold orientation. More generally, however, the lineation girdle indicates multiple deformation. The stereonet plots in domain III have similarities to those in domains to the north and to domains V and VII to the west. Since those areas have greatly different fabrics, it is uncertain whether domain III is a transitional domain or whether its boundaries might better have been selected to separate unlike fabrics, probably the latter.

Domain IV

Domain IV is characterized by thick Skajit Limestone and widespread Mississippian rocks. The area is broken by numerous imbricate thrust faults, probably folded. Complex structural features are marked by the color contrast between the major units but are by no means well delineated. Obvious large folds are few; small-scale folds of diverse orientation and style are numerous. Commonly the schistose rocks and phyllites show pervasive small-scale shear folding. The "limestone" is almost everywhere recrystallized to marble with little or no preservation of sedimentary structures or texture. The crude layering that can be seen from a distance may or may not represent bedding but probably does; in outcrop, the marbles are little more than a mosaic of coarse-grained calcite.

The S-surfaces and axial planes coincide and are nearly horizontal. Although there is a prominent, flat north lineation, the lineations generally plot as a horizontal large-circle girdle. The simplest explanation for the coincidence of foliation and axial planes is a recumbent isoclinal fold system. That the flat north lineation is the axis of such a fold system is uncertain; it could represent inherited pre-isoclinal fold deformation. The large-circle girdle plot of lineation indicates multiple deformation, complicating the apparent simplicity of the S-surfaces and axial planes. Some of the complexity may be caused by an unconformity at the base of the Mississippian rocks.

Domain V and VII

Domains V and VII contain a complexly deformed, heterogeneous sequence composed mainly of carbonates and various medium-grained schists. Folds are highly diverse styles; they include several large open folds with crenulated limbs and numerous recumbent isoclinal and intrafolial folds at various scales. Small-scale shear folding is common in the schists. The carbonates are largely recrystallized to marble and commonly rheomorphically deformed.

The stereonet plots in both domains show patterns similar to those in domain IV. The only difference is that the orientations of the axial planes in domain VII, which includes most of the contact zone of the Devonian plutons, are markedly more diverse than those in domains IV and V, though similarly centered. The structural interpretation of the structure for domains V and VII is the same as that given for domain IV.

Although the Arrigetch Peaks and Mount Igikpak plutons probably merge at depth below much of these domains, the deformation that can be attributed to the intrusion of granite in adjacent metamorphic rocks is apparently moderate to minor. The most obvious effect of intrusion is doming of the metamorphic rocks over the northeastern lobe of the Mount Igikpak pluton. Doming probably occurs widely over the plutons but is less evident elsewhere. More intense deformation, complex folding in particular, is evident near the contacts of the plutons but may not be markedly more common there than elsewhere in the domains.

Domain VI

Domain VI is entirely of Devonian granitic orthogneiss.

Large folds are present in several localities (notably in T. 22 N., R. 29 and 30 E.), and small-scale folds occur in several other localities. The internal structure of the granites is poorly understood because of the reconnaissance nature of our work and the difficulty in determining the texture and structures in the granites from more than a few meters away.

The stereonet plots indicate a simple cylindrical fold system oriented northwest. The few shallowly dipping northwest lineations support a northwest-trending fold system. Both the foliation and the lineations in the granites form an orientation unique in the quadrangle; they do not coincide with the orientation of those structural elements in any other domain. The plots seem to represent a single stage of deformation that cannot be accommodated to the structural interpretation of adjacent domains. As stated, the structural fabric is probably related to Devonian orogeny and an incompletely understood sequence of metamorphism, intrusion, uplift, and mineralization, but the fabric and its discordant trends may have developed later, possibly during the Cretaceous. Whenever formed, the structural fabric may reflect the homogeneity of the granite relative to the adjacent heterogeneous layered metamorphic rocks. The granites may more faithfully represent the regional stress patterns than do other rocks in the quadrangle. The interpretations given here and any conclusions drawn from the data should be accepted provisionally because of the sparsity of the data.

Domains VIII and IX

Domains VIII and IX coincide with the schist belt, a sequence of low-grade metamorphic rocks with few carbonates. The domains were originally divided arbitrarily at the Reed River, but the rocks differ somewhat in the two domains. To the west in domain VIII, most of the rocks are micaceous schists. In addition, a heterogeneous sequence, the so-called "package rocks" of the mining industry that host volcanogenic copper-zinc deposits of felsic schist, metarhyolite, quartz-muscovite schist, limestone and greenstone, is prominent in the western schist belt. To the east in domain IX, there are few marker horizons and apparently few or none of the package rocks but rather a series of east-trending micaceous schists with variable chloritoid and albite.

Small-scale shear folding is ubiquitous in the schists. In domain IX, the structure appears relatively simple with east-west continuity of units from at least Walker Lake to Iniakuk Lake. The simplicity is probably deceptive because of the absence of marker units. In domain VIII, the distinctive units of the package rocks reveal complex patterns of folding and faulting which have been mapped in detail by industry geologists. In the eastern part of domain VIII, in T. 19 and 20 N., R. 17 and 18 E., high-angle faults offset refolded isoclinal folds associated with copper-zinc mineralization (Marrs, 1978).

The structural data for domains VIII and IX are similar. The S-surfaces, which plot as a north-south great-circle girdle, suggest a simple cylindrical fold system oriented about N. 80° E. with dominance of southward-dipping limbs. This simplicity is surprising in the face of the structural complexity seen in outcrop at many places and in thin sections, which show at least three episodes of deformation. Flat lineations in both domains form a maximum at about N. 70° E., an orientation slightly oblique to what would be expected to a fold axis related to the girdle of the S-surfaces. Lineations that form a weak large-circle girdle striking about N. 70° E. and dipping southeast at about 20° indicate several periods of deformation.

Any interpretation of the structural data based entirely on the simple north-south girdle formed by the S-surfaces and the strong lineation maxima is demonstrably overly simple. Private industry and the Alaska Division of Geological and Geophysical Surveys have mapped extensively and in detail in the schist belt of domain VIII and westward into the Ambler River quadrangle in their exploration of the volcanogenic copper-zinc deposits associated with the package rocks. Their work indicates that the schist belt is characterized by refolded isoclinal folds and at least three major and many minor northward-dipping east-trending faults. Smith and others (1977) indicate a gradational structural style across the schist belt that ranges from simple south-dipping units with minor folding on the south to tight isoclinal folding northward toward the core of the schist belt, which then merges into complex polyclinal folding in the north. At Ruby Ridge in the Ambler River quadrangle, Gilbert and others (1977) document a complex faulted structure marked by numerous isoclinal folds with at least two periods of metamorphism and penetrative deformation. Superimposed on the two older deformations is the Kalurivik arch, a broad (Cretaceous?) antiform that trends about N. 70° W. for about 60 km in the Ambler River quadrangle (Pessel and others, 1973; Gilbert and others, 1977; Mayfield and Tailleur, 1978). This arch extends about 15 km into the Survey Pass quadrangle (T. 20 N., R. 13 and 14 E.); it is overturned to the south at its east end and finally loses its identity in the regional foliation.

Domain X

Domain X is primarily of Paleozoic to Triassic basalt and dark-gray phyllite. It is part of an extensive terrane as much as 10 km wide that extends for at least 400 km along the south side of the Brooks Range, notably in the Angayucham Mountains just south of the Survey Pass quadrangle, but is barely exposed in this quadrangle. The north boundary of the domain coincides with a topographic depression, commonly referred to as the Kobuk trench or lineament, a major regional discontinuity that separates Paleozoic rocks of the Brooks Range from the belt of basalts and Mesozoic sediments of the Yukon-Koyukuk Basin. The structural data are too sparse for interpretation other than that the bedding and schistocity generally dip southward.

TECTONOSTRATIGRAPHIC TERRANES

The rocks of the Survey Pass quadrangle are divisible into six terranes (fig. 1), each characterized by a distinct combination of stratigraphy, structural style, and metamorphic grade (see Nelson and Grybeck, 1981). The terranes coincide with the domains already discussed or aggregates of domains grouped because of similar structural fabric and lithology. Within the limits of this preliminary study, the six terranes are the minimum number of homogeneous regional tectonostratigraphic units into which the quadrangle can be divided. The division of the quadrangle into terranes does not rest on the structural interpretations of individual domains, as those interpretations are likely to be overly simple. However, the orientations of the structural fabrics in the various terranes show marked differences that cannot be simply related to one another structurally. The S-surfaces in domains V and VII of the central terrane, for example, plot as a pronounced flat maxima, whereas the lineations show strong shallow-dipping north maxima. In contrast, the S-surfaces in the adjacent schist belt, domains VIII and IX, plot as north-south girdles and the lineation show flat maxima at about N. 70° E.

Northern Terrane

The northern terrane, domains I and II, is occupied by a thick Upper Devonian sequence that consists mainly of the Hunt Fork Shale and its upper sandstone member, an unnamed gray phyllite unit, various members of the Kanayut Conglomerate, and Mississippian through Triassic marine sediments exposed here and there in synclines, weakly metamorphosed to unmetamorphosed and subject to only one penetrative deformation. Large open parallel folds are common; small-scale shear folds and kink banding are pervasive in the shales. The structural data indicate an east-west, cylindrical fold system with flat, east-west axes and divergent axial planes.

The Kanayut Conglomerate and Hunt Fork Shale that make up most of the northern terrane are widely considered to be a clastic wedge derived from the north (Brosgé and Dutro, 1973, for example). But the actual position of their depositional setting in Devonian time is in dispute; their source may be northward only in terms of present-day geology. In 1970, Tailleur and Brosgé suggested that the source of the Upper Devonian clastic sediments lay in the Canadian Arctic islands but that the present position of the Kanayut Conglomerate and Hunt Fork Shale is far removed from their source area because of counterclockwise rotation of northern Alaska in Jurassic and Cretaceous time. In contrast, Mull argues that the Kanayut Conglomerate and the Hunt Fork Shale were obducted in post-Triassic time at least 150 km northward over what is now the core of the Brooks Range (oral commun., 1978; Mull and others, 1977; Nawman and others, 1979; Roeder and Mull, 1978). The units would still have a northern source but would be a Devonian highland formed of the pre-Late Devonian rocks of what is now the core of the Brooks Range rather than the Canadian Arctic islands. Numerous other workers have suggested a northern, now unexposed source for the Kanayut Conglomerate and Hunt Fork Shale under the post-Devonian sedimentary rocks of the Arctic Coast or northern part of Alaska.

West-Central Terrane

The west-central terrane, domain IV, is mainly of the thick Skajit Limestone associated with unnamed gray to black calcareous phyllite units unconformably(?) overlain by the Mississippian Kakiktuk Conglomerate and Kayak Shale. The Hunt Fork Shale of the northern terrane may be represented by calcareous phyllite, but the rest of the thick Upper Devonian section in the northern terrane is absent here. The terrane is extensively thrust faulted; some thrusts are probably folded. All units are relatively highly deformed; evidence of transposition and small-scale shear folding is common; sedimentary textures and bedding are largely obliterated. Foliation and axial planes suggest that the major structures are flat isoclinal folds. The lineations do not indicate an unambiguous orientation to these folds but do indicate multiple periods of deformation of which the isoclinal system is probably only the latest.

Central Terrane

The central terrane, domains V through VII, is mainly the Skajit Limestone, commonly interbedded with chlorite schists and various medium-grade schists. Because fossils are notably absent, only the Silurian and Devonian Skajit Limestone can be correlated with assurance. The intrusion of Devonian granite indicates that most of the metamorphic rocks are Devonian or older. The thick Upper Devonian clastic-wedge section of the northern terrane is absent, as are Mississippian rocks. Folds are common at all scales, but neither their style nor vergence is consistent. Deformation is relatively great; the rocks behaved much more plastically than in the northern terrane. The structural fabric is similar to that in the west-central terrane, domain IV. Flat foliation and axial planes suggest a major fold system of flat isoclinal folds. The lineations do not indicate a unique orientation to this isoclinal system but do suggest multiple deformation. The Devonian granite that intrudes this terrane probably underwent much of the deformation associated with the terrane. The pervasive foliation pattern in the granite is interpreted as a post-intrusion episode of the Devonian syntectonic forces that generated the granite itself and elevated the central terrane to amphibolite-facies metamorphic rocks prior to intrusion. The orientation of the foliation in the granite, northwest in trend, differs from that in adjacent rocks in this terrane or any other in the quadrangle.

The relation of domain III to the six terranes defined is unclear. Domain III is mainly of the thick Skajit Limestone and related rocks with a band of the Hunt Fork Shale and a discontinuous belt of Mississippian quartzite in the northern part. The carbonate rocks are almost entirely recrystallized and commonly folded plastically. The stereonet data show structural similarities to both the northern terrane and the central terrane. We tentatively propose that domain III is the eastward extension of the central terrane. The northern part of domain III may, however, be the eastward extension of domain IV. The source of Precambrian granitic schist at the eastern boundary of the quadrangle in domain III is enigmatic. Except for its age, the schist would seem to be a schistose equivalent of the Devonian foliated pluton in the central part of the quadrangle, but its Precambrian uranium-lead age suggests the presence of a poorly defined Precambrian basement in the central Brooks Range.

Schist Belt Terrane

The schist belt, domains VIII and IX, is mostly various low-grade schist with only minor carbonate rocks and a discontinuous heterogeneous unit, the package rocks that host large copper-zinc deposits. The carbonate rock and metarhyolite in the package rocks are probably Devonian, but rocks as old as Precambrian and as young as Triassic may occur in the terrane. None of the rocks in this terrane has an ambiguous stratigraphic equivalent in rocks of terranes to the north. The northern boundary of the terrane is the so-called Walker Lake lineament, a major structural break but not a simple one. It is probably a folded unconformity or thrust fault. The terrane is pervasively folded; the most ubiquitous folds are small-scale shear folds. Where marker units are present, refolded isoclinal folds and high-angle faults can be identified. Bedding is largely or entirely transposed, although the east-west regional continuity of metamorphic rock units may represent original sedimentary trends. As many as three periods of deformation can be identified in outcrop. The foliation and axial planes indicate a dominant fold system of east-west isoclinal folds with flat axes at about N. 70° E. The field relations as well as the divergent fold axes and axial planes belie such simplicity and indicate that the isoclinal folds mask much greater complexity and multiple deformation.

Angayucham Terrane

The Angayucham terrane, domain X, is largely basalt with substantial phyllite and scattered Ordovician to Devonian limestone, rare Mississippian chert, and widespread Triassic chert. The terrane is subject to two interpretations. One is that two ages of basalt are involved. Following the two-basalt interpretation, the older is Paleozoic; the critical point of interpretation is that some of the fossiliferous Ordovician to Mississippian limestone is interbedded with the basalt. The younger basalt is associated with Triassic cherts. The alternative interpretation is that the Paleozoic limestone is not interbedded with basalt but occurs as fault slivers or xenoliths. All of the basalt is then of Triassic or younger age. Our slightly preferred interpretation is that the block is a Mesozoic melange whose northern boundary marks a subduction or collision zone. This interpretation requires that the Paleozoic limestone occurs as fault slivers or (commonly concordant) xenoliths. However, basalts of two ages may be present.

By either of these interpretations, the basalt probably represents a melange or a southward-dipping(?) subduction or collision complex that marks the limit of the Mesozoic thrust plates of the Brooks Range. Patton and others (1977), Mull (1977), and Roeder and Mull (1978) consider this basalt unit to be part of an ophiolite belt that is the root zone for an obducted slab thrust northward over the Brooks Range for at least 120 km. The slab is now mostly eroded away, but isolated klippen remain as large mafic and ultramafic complexes in the DeLong Mountains northwest of the Survey Pass quadrangle. Forbes and others (1979) see no tectonic relation between the ophiolites and the scattered occurrences of blueschists in the schist belt because potassium-argon dates for glaucophane from the blueschist are Precambrian, and thus much older than the ophiolites emplaced during the Cretaceous. However, Patton and others (1977) question this supposedly coincidental association of ophiolites with blueschists because the association is a regional one that marks the perimeter of the Yukon-Koyukuk Basin for more than 1000 km. The obduction theory further requires that the structural break at the Kobuk trench mark the collision zone or the southern boundary of the now-collapsed source for the Devonian sedimentary rocks, which, like the ophiolites, were obducted to the north. These obducted Devonian rocks make up most of the section in domain I, notably the Kanayut Conglomerate. Other workers suggest that the structural break at the Kobuk trench is not nearly so profound as required by the obduction theory. Smith and others (1978) argue that the basalts (Devonian in their interpretation) are nearby equivalents of rocks in the schist belt.

Granitic Terrane

The relation of the granitic terrane to the other terranes is not clear. Although this terrane occurs within the central terrane, a small stock of apparently similar granite occurs within the schist belt (T. 20 N., R. 16 E.). Although the large plutons of the granite terrane probably merge at depth to form a batholithic body under the central part of the quadrangle, the aeromagnetic data do not substantiate its extension under the schist belt (Cady and Hackett, 1981). They do not reject it, however, and the small southern granite body may be an apophysis of the plutons of the granitic terrane. Alternatively, the juxtaposition of the central terrane and the schist belt is a post-intrusive event, and the geographic association of the small pluton and the granitic terrane is a result of faulting, or coincidental. Yet another possibility for the association of the plutons is that the domain boundary does not truly reflect the geologic boundary. The area of schist belt-like rocks adjacent to the small pluton in T. 20 N., R. 16 E. might better be included in domain V, a correlation suggested by the metamorphic-grade map (Nelson and Grybeck, 1981).

The Devonian granites and Devonian clastic wedge rocks of domain I are coeval within the limitations of the dating methods. Both the Hunt Fork Shale and the Kanayut Conglomerate are Late Devonian (Famennian) according to Dutro, Brosgé, and Reiser (1977); the (slightly younger?) granites give a uranium-lead age of 360±10 m.y. (Dillon and others, 1980) and a rubidium-strontium whole-rock isochron age of 373±25 m.y. (Silberman and others, 1979). It is tempting to consider the orogeny marked by these plutons exposed in the Survey Pass quadrangle as the source for the Devonian clastic wedge despite the apparent northern source for the sediments.

SUMMARY

Six geologic terranes of the Survey Pass quadrangle are differentiated by lithology or stratigraphy, divergent structural fabric, and sharp breaks in metamorphic grade. These terranes are not "blocks" or "microplates" in the sense of crustal blocks with vertical continuity to the mantle. Rather, they are north-dipping plates or slabs generally bounded by the prominent east-trending thrust faults that largely mark the formation boundaries in the quadrangle (see especially the cross section in Nelson and Grybeck, 1980). As such, they are undoubtedly structurally related to the thrust-bounded stratigraphic sequences identified widely in northwestern Alaska by Tailleur and others (Tailleur and Brosgé, 1970; Mayfield and others, 1978), Martin (1970), and Churkin and others (1979). These terranes probably continue eastward into the Wiseman quadrangle as the sequences of rock units defined by Brosgé and Reiser (1971).

The marked differences in lithology or stratigraphy between terranes that commonly involve coeval or possibly coeval rocks strongly suggest juxtaposition of rocks once far separated. Our studies indicate little about the age of terranes in the Survey Pass quadrangle. Studies made elsewhere in the Brooks Range (Mull, 1977; Roeder and Mull, 1978; Tailleur and Brosgé, 1970; and Churkin and others, 1979, among others) strongly suggest that these terranes were largely thrust over one another in Cretaceous time.

Despite varying fold styles, complex geology, and differing structural fabric, a recurring feature of the southern two-thirds of the quadrangle, notable in both outcrop and our structural interpretations, is recumbent isoclinal folds. Their ubiquity indicates great foreshortening of the stratigraphic section and suggests the presence of even larger recumbent, isoclinal folds.

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