Devon Canada Corporation

Nahanni Butte Geologic Fieldwork Report

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Alexis Anastas

Chris Bergquist

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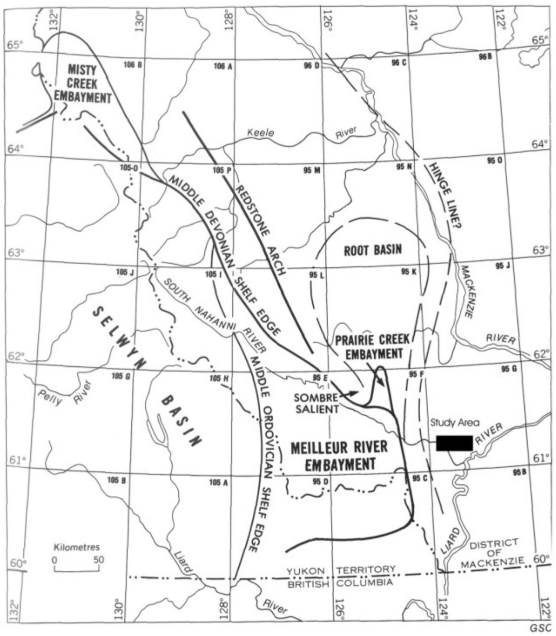
MISTY CREEK EMBAYMENT
Keele River
HINGE LINE?
MIDDLE DEVONIAN SHELF EDGE
REDSTONE ARCH
ROOT BASIN
MACKENZIE RIVER
SOUTH NAHANNI RIVER
SELWYN BASIN
PRAIRIE CREEK EMBAYMENT
SOMBRE SALIENT
Pelly River
MIDDLE ORDOVICIAN SHELF EDGE
Study Area
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BRITISH COLUMBIA
Liard River
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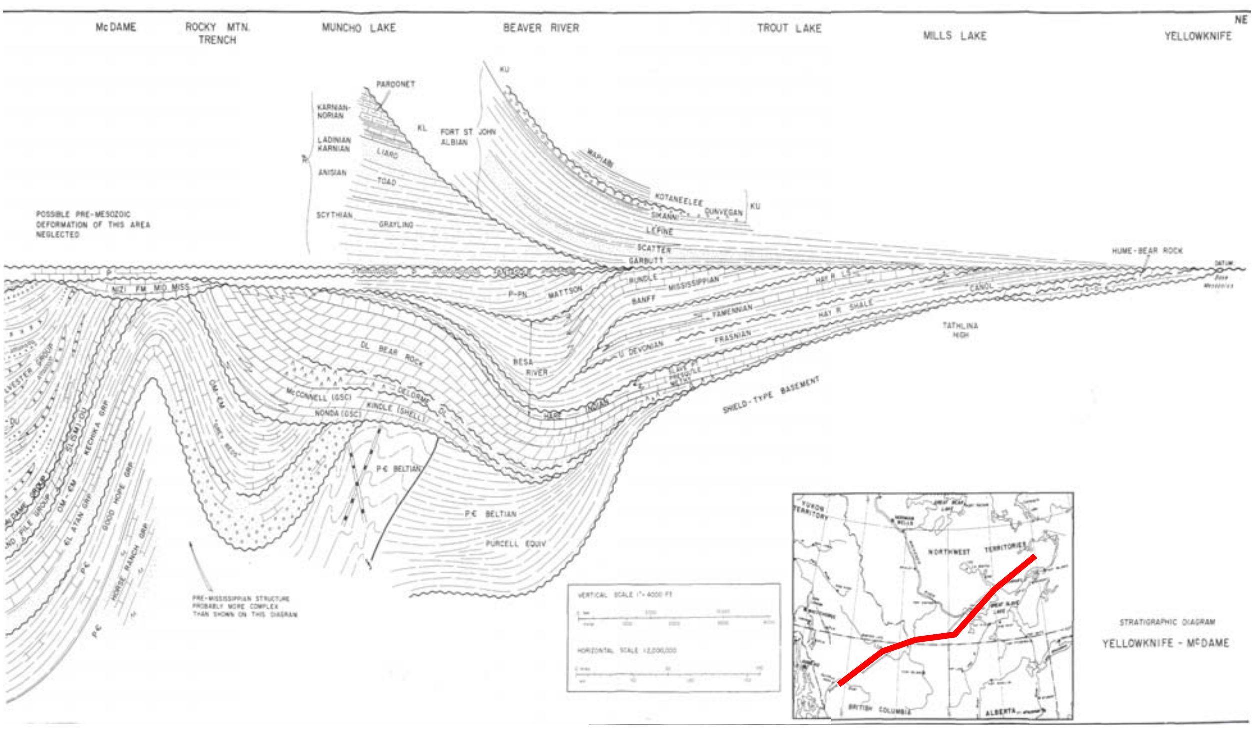
McDAME
ROCKY MTN. TRENCH
MUNCHO LAKE
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POSSIBLE PRE-MESOZOIC DEFORMATION OF THIS AREA NEGLECTED
PARDONET
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DUNVEGAN
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MATTSON
BANFF
MISSISSIPPIAN
FAMENNIAN
FRASNIAN
HAY R. SHALE
CANOL
TATHLINA HIGH
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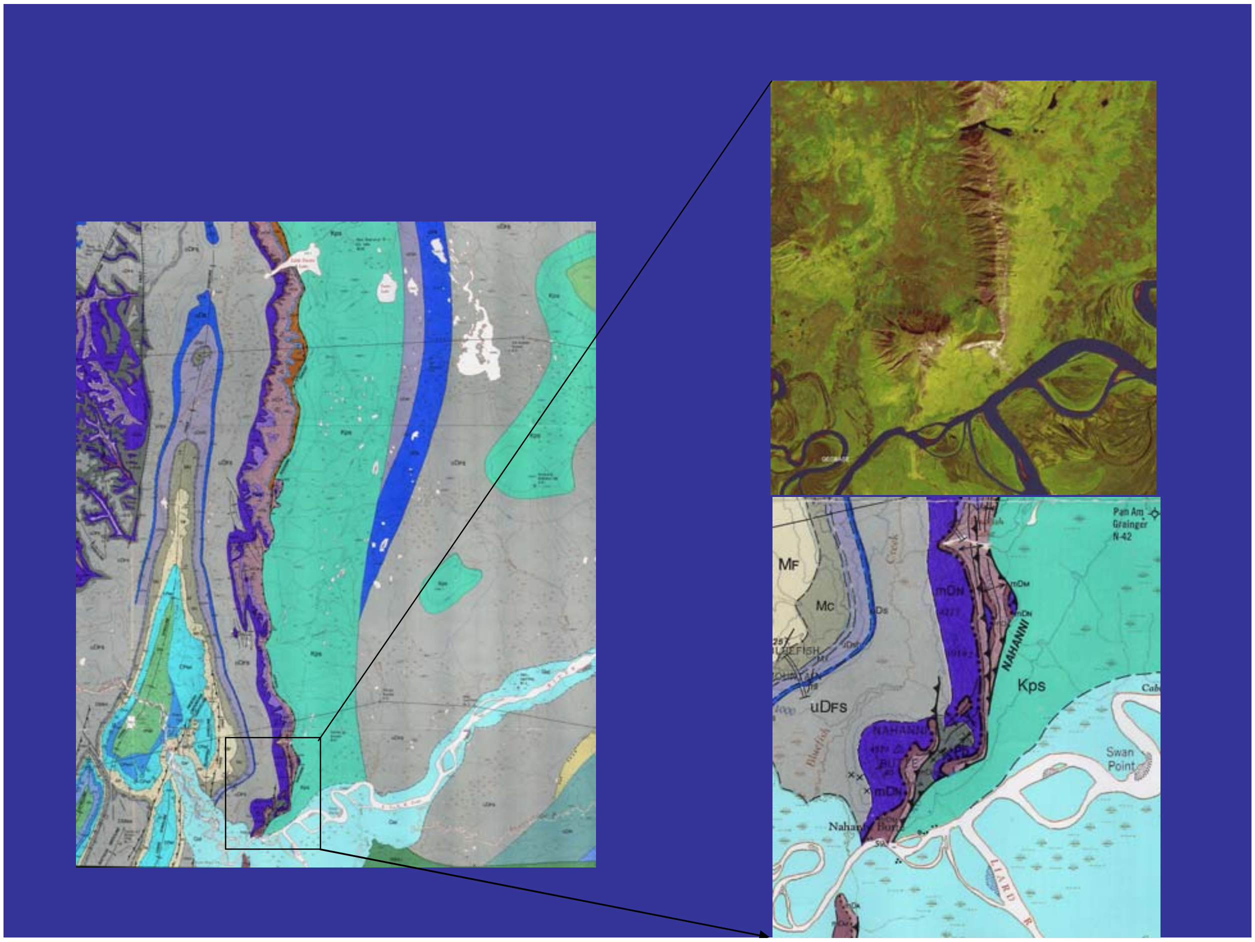
NORTHWEST TERRITORIES
BRITISH COLUMBIA
ALBERTA
STRATIGRAPHIC DIAGRAM
YELLOWKNIFE - McDAME



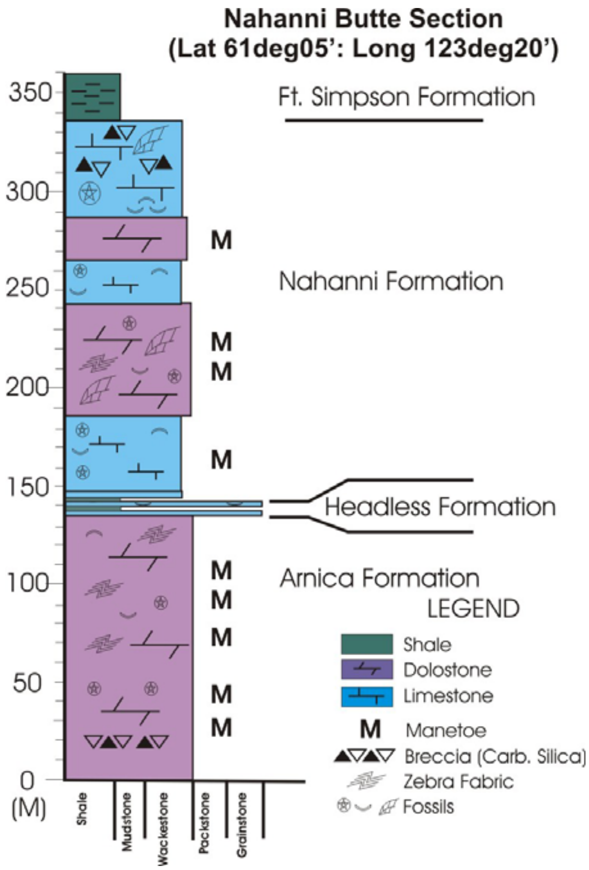
STRATIGRAPHY AND DIAGENESIS (Alexis Anastas)

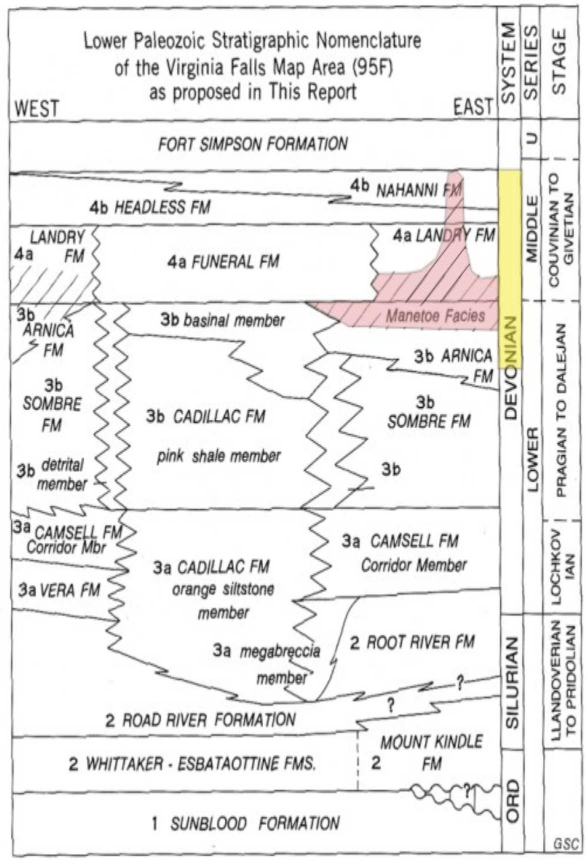
Background

Devon's Field work in the Nahanni Range, NWT area yielded a number of insights regarding the depositional and subsequent diagenesis of the Middle Devonian carbonate section. Samples were taken from the Nahanni – Arnica interval focused on the Manetoe and brecciated facies (Fig. 1). A number of these samples were thin sectioned, stained and examined.

Figure 3: Stratigraphic Section at Nahanni Butte

Figure 2: Correlation Chart showing stratigraphy of interest (yellow) and Manetoe (Pink)





Stratigraphy

Devon's Fieldwork in the Nahanni range focused on the Middle Devonian Carbonates deposited at the NW edge of the broad Mackenzie Shelf-Elk Point carbonate platform that covered much of the WCSB (Fig. 2). The units encountered in the field are shown in Fig. 3 Nahanni Butte which is a stratigraphic section logged by the Geological survey of Canada in the Nahanni Butte area. The stratigraphic framework for the unit described in this report is taken directly from Morrow and Cook (1987).

Arnica Formation

At its exposure in the Nahanni Range area, the Arnica Fm. is a 120-150 m thick section of fine to medium bedded, brown to grey dolostones. The unit is a cyclical succession of subtidal wackestones shallowing upwards into shallower water intertidal muddy dolostones with abundant cryptalgal laminates. The rocks contain typical shallow water features such as birdseye textures, cryptalgal lamination, intraclasts, and flat pebble conglomerates. It has a basal unit which frequently contains megabreccias suggestive of deposition on an appreciable slope. A Pragian to Zlichovian age is denotes by conodont samples.

Landry Formation

The Landry Fm is not specifically identified in the Nahanni Range area but is a brown- bluish-grey pelloidal wackestone-packstone overlying and passing shorewards into the Arnica. It is sparsely fossiliferous with some ostracods and calcispheres. It reaches a maximum thickness of over 100 m north of the study area. I may be a shelf margin facies of the Arnica dolostones but due to its being commonly obscured by the Manetoe Facies, not much is know regarding its origin..

Headless Formation

The Headless Fm is a 4-10 m unit in the Nahanni Range that is composed of green-grey argillacous limestones and recessive shales. It is an open marine unit with mud clasts with crinoids, brachiopods and occasional charophytes. It is a basinal unit part of a transgressive pulse and thickens westand northwards. Conodonts show it to be Eifelian. In the Nahanni Range it was a 4-6 m apple-green shale at the top of the Arnica. Most stratiform Manetoe was below this stratigraphic level.

Nahanni Formation

This unit reaches a thickness 190-200 m in the Nahanni Butte area and is composed of medium to thick bedded, lt-med grey limestones (Wackestones packstones and rare grainstones). The unit is often cliff-forming and contains abundant open marine fossils including stromatoporoids, brachiopods, rugose and tabulate corals and pelecypods. It is a horizontally bedded muddy and biostromal unit created by subtidal open shelf level-bottom communities deposited on a rimmed shelf to a distally steepened ramp. Burrow mottling and and bitumen staining is common. The Nahanni is Eifelian to Givetian in age and is overlain by middle-Devonian – Mississippian Ft. Simpson Shales. It passes basinwards into the Funeral-Headless-Ft. Simpson Shales and shorewards into the Upper Chinchaga and lower Keg River Fm. limestones which constitute a broad widespread platform during Elk Point time. Overall the Nahanni is a transgressive (deepening upwards) succession overlain by shale at a ”drowning unconformity”. Transgression caused the locus of carbonate deposition to retreat southwards to the Pine Point Presque Ille Barrier which formed a massive reefal edifce as it kept up with relative sea level. This barrier created the Elk Point evaporate basin.

Manetoe Facies

The Manetoe facies is a regional and widespread mappable dolostone unit which owes it origin to the extensive and polyphase diagenetic alteration of the Arnica, Landry, and Nahanni formations. The Manetoe is dramatically different from the precursor carbonates as it contains ubiquitous coarse crystalline dolomite, breccia layers and zones, and large megapores filled with dolostone. The units were examined in detail in the Nahanni Range area of NWT (see posters). The Manetoe Facies was created by a number of processes (Phases) and as a result displays a combination of overprinted fabrics and large scale sedimentary/diagenetic features. The origin of these processes is still in debate. Morrow et al (1990) have suggested that the Liard Basin wa an area of high heat flow during the Paleozoic due to its proximity to the western margin of the craton.

Phase 1: Bed-confined solution collapse and dolomitization

Phase 1 constitutes a widespread fabric-obliteritive dolomitization. The processes appears to have begun with an intense leaching of the limestone and development of bedding parallel sheet cracks 1-5cm wide that was followed by roof collapse and disturbance of the remaining rock. Morrow et al. suggest this was a result of extensive meteoric karsting. After this it appears that the host rock was pervasively dolomitized to a med-dark grey dolostone. Finally the voids were filled with white to lt. Yellow saddle dolomite. This processes was largely confined to beds with solution cavities being <10-20 cm wide. This processes was fabric selective as it only occurs in parts of the Landry-upper Arnica. This Phase formed "zebra" dolomite fabrics famous for the Presque Ille, Manetoe and MVT deposits (e.g. Pine Point, Viburnum Trend). Phase 1 Manetoe Facies is abundant and laterally extensive at the Landry-Upper Arnica level where it is a correlatable unit o the east and south. Fluid inclusions from the saddle dolomite suggest superheated brines (Morrow et al. 1990).

Phase 2: Large scale collapse and cementation

Observation by helicopter and field transects showed large areas (1-100 m) of structural disturbance that seems to be rooted in bedding perpendicular fractures. These fractures appear to be associated with dissolution related dilation (removal of rock) and consequent roof collapse.

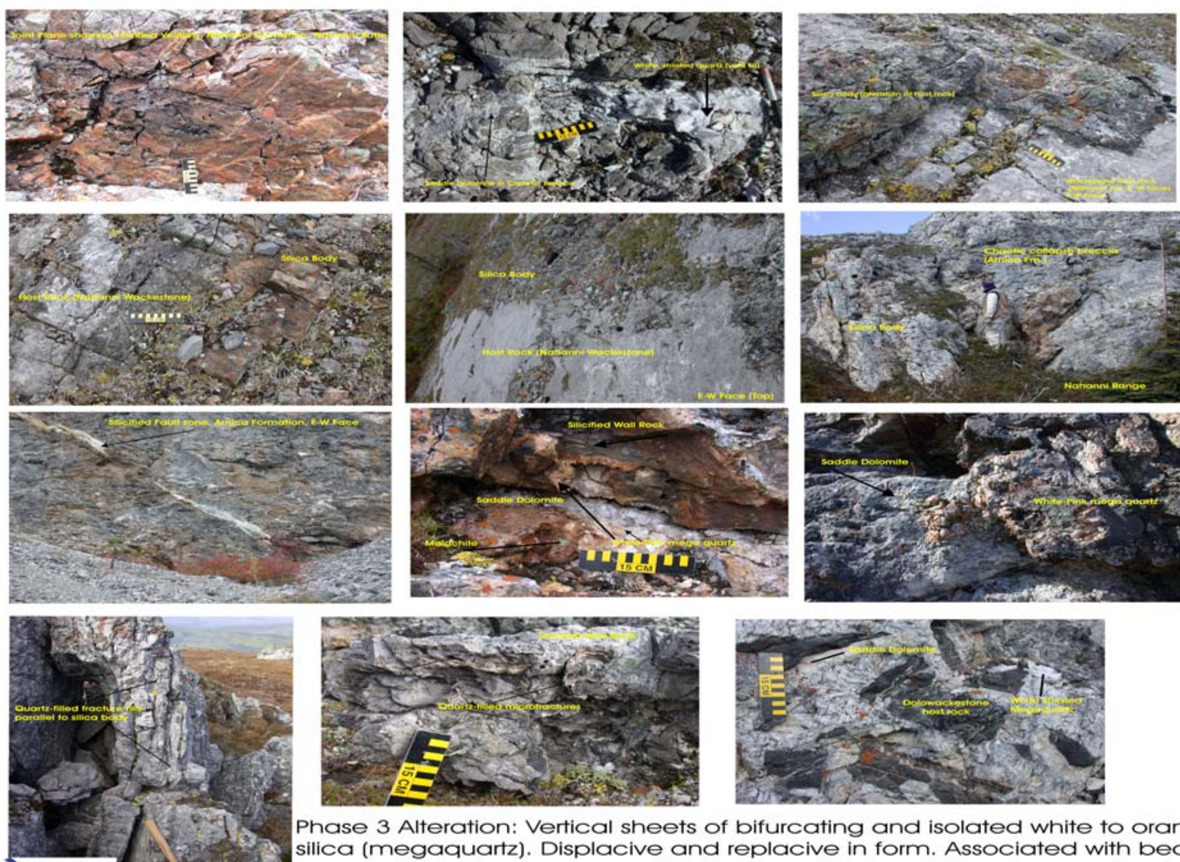
Open space was occluded with massive saddle dolomite and breccia clasts creating what appears at the present day. Clasts of phase 1 dolomite are in the spaces and are touching and "floating" in saddle dolomite cement. This type of Manetoe Facies occurs at the Arnica Level and forms "intrusions" upwards into the Nahanni (see Fig 2, Fig. DCSN 6660,). These bodies are alteration and collapse zones related to large vertical fractures (see above). In some cases the zones are rooted in stratiform Manetoe (Phase 1) while some times they die out into fracture zones. Some areas show clasts of strata that appear to have been pushed upwards from their regional level suggesting fluids came from the bottom upwards (Fig. DSCN 6660). These types of upwards intrusions into the Nahanni are what seems to have occurred in the area of Kotaneelee and Pointed Mountain. Though the massive saddle dolomite are not porous, they are associated with leached, dolomitized matrix and fossils.

Phase 3: Fracturing, silicification and mineralization

This process and its results overprints the aforementioned Phases. The Large East west face and one locality 10 km (?) north of the Nahanni Range show evidence of large scale fracturing and dilation. In once case the fracture was <2m across in the Arnica but when the same fracture was traced up to the Nahanni (200-300 m), it had bifurcated a number of times and was a fracture zone about 50-75 m wide. These fractures were always associated with silicification of the surrounding host rock and abundant coarse crystalline quartz. Infill. Silicification extended 1-10 m into the host rock and was moderately fabric preservative.

Euhedral megaquartz crystals are coarse (1-5 cm wide), pegmatitic and suggest slow precipitation from silica-rich hydrothermal fluids. Rims of megaquartz are overlain by thick saddle dolomite cements that show characteristic warped saddle form (see Figure). Malachite and Azurite, common in hydrothermal systems, were found on the rims of megaquartz. Phase 3 silica bodies probably occurred in the same areas and overprinted the main saddle-dolomite cemented breccias. Morrow et al (1990) suggest that silicification occurred from top to bottom and related to deep burial silica remobilization.

Phase 3 Alteration



devon

Phase 3 Alteration: Vertical sheets of bifurcating and isolated white to orange silica (megaquartz). Displacive and replacive in form. Associated with bed perpendicular fracture zones. Silicification of Nahanni Limestone wall rock. High temperature copper carbonates and sulphides.

Reservoir Implications

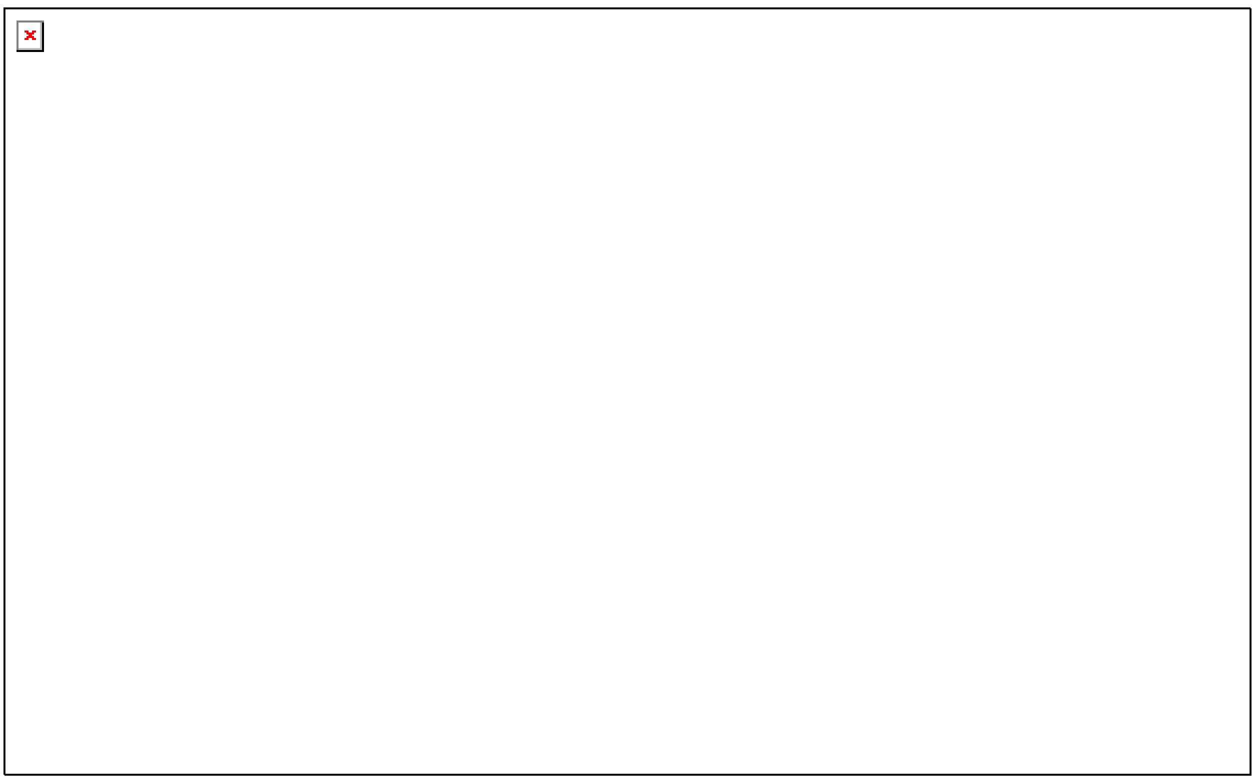
The stratigraphic and diagenetic observations taken field work and afterwards have numerous implications towards reservoir in the Manetoe and related facies.

Breccia Cores

The breccias in the Nahanni and the Arnica show abundant and pervasive void–filling cementation (Phase 2 Alteration). This suggests that the porosity and permeability of these "core" areas are low leading to poor reservoir quality. This is similar to what is suggested by Graham Davies in his Report. However, it should be noted that we found very little good reservoir quality rock in the Middle Devonian section during the trip so this may be an artifact of sampling. If similarly cemented in the subsurface, these would represent tight zones in reservoirs. If these areas are much less cemented, they would represent zones of high Kh and Kv. Considering that matrix Nahanni Dolomite has very low K, breccia zones would connect reservoir intervals at different levels, and may explain the early breakthrough of water and lack of fractures encountered in core.

Silica Bodies

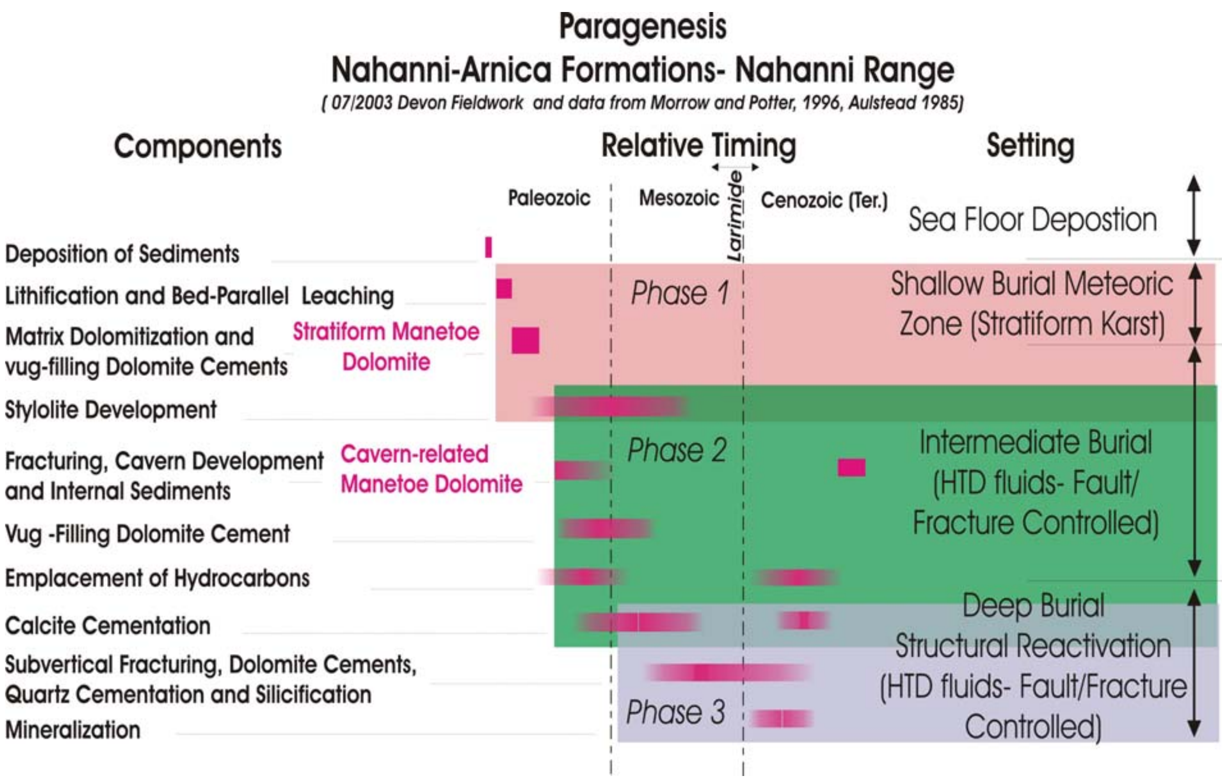
Stage 3 alteration silica bodies, as noted above, were encountered all over Nahanni Butte and in a large part of the East – West Face outcrop. It was encountered in some areas to the north in the Nahanni Range. These bodies cross-cut large amounts of the stratigraphy (Top Nahanni to Mid Arnica) and were associated with Phase 2 breccias and faulted zones (see above). The same discussion and implications low and high Perm zones in Breccia Cores can be applied to Silica bodies.. This could act as a water or hydrocarbon conduit or a reservoir compartmentalizing fault. The Silica bodies cross-cut the small amount of Headless Shale in the section no longer making it a bottom seal for hydrocarbons or water.



Timing

The timing of phases is 1-3. The main pervasive alteration of the matrix rock was in phase 1. Hydrocarbon emplacement was post Manetoe Dolomite (Morrow et al, 1990). Morrow et al (1990) shows that quartz in some areas of the subsurface contain methane inclusions suggesting their formation as pre-syn hydrocarbon emplacement (Paleozoic). The main reservoir porosity in the Kotaneelee Field is the abundant vuggy and fractured dark grey dolowackestones. This probably occurred a the same time as phase 1-2 in the Nahanni Range as this was the most similar and pervasive event. The silica bodies appear to be after Phase 2 (hence Phase 3) but not very long after as the saddle dolomites and the megaquartz are commonly intergrown. Morrow et al (1990) suggest the silica was remobilized deep in the section and possibly sourced from the shales. Galena, Malachite and Azurite, found on megaquartz cements, are high temperature ore minerals precipitated after (Mesozoic ?- Morrow et al, 1990).

Figure 5: Diagram of Mineral Stages



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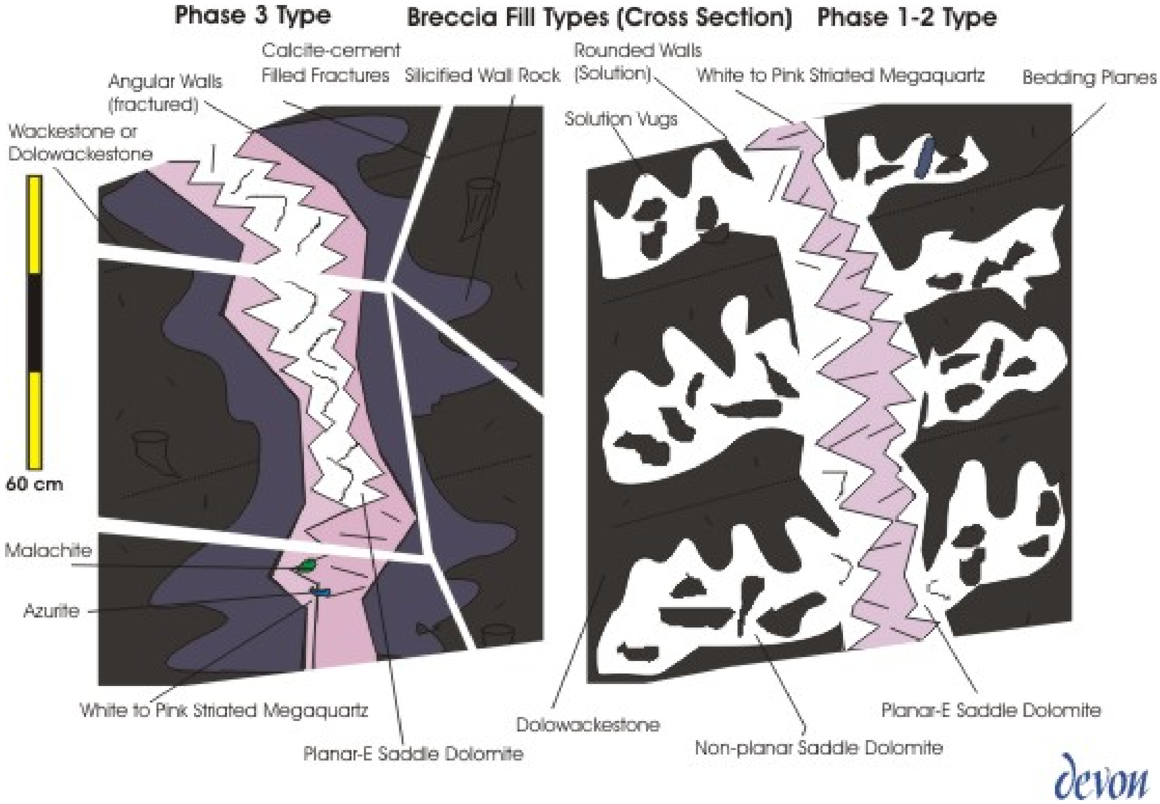
Morrow, D, Cummings, G. and Aulstead, K. (1990) The Gas-Bearing Devonian Manetoe Facies, Yukon and Northwest Territories, GSC Bulletin 400.

Morrow, D. and Cook, D. (1987) The Prairie Creek Embayment and lower Paleozoic strata of the Southern Mackenzie Mountains, GSC Memoir 412.



STRUCTURAL INTERPRETATION (Jamie Jamieson)

The structural aspects of the Nahanni Butte field work fall into two general categories: (1) investigation of the general style and geometry of structures that involve the Devonian carbonate section and (2) assessment of the general characteristics of the fracture systems that are developed within the Manetoe facies of the Devonian carbonate section.

Structural style and geometry

Our major focus was on the structure of the Nahanni Range (Figs. S4 to S8), including Nahanni Butte and the E-W Ridge (Figs. S1 to S3). The latter two features are both very prominent, and somewhat unusual, structures located at the southern limit of the Nahanni Range. We also made a brief investigation of the southern Headless Range structure (south of the Nahanni River, Fig. S9) and the western flank of Prairie Creek Anticline (north of the Nahanni River, Figs. S10 to S14).

The Nahanni Range is a N-S trending ridge that extends 100 km, from the Nahanni River drainage (on the south) to the Tetcela River drainage on the north. The underlying structure here is a system of west-dipping, east-verging thrust faults carrying km-scale hangingwall anticlines. These folds have planar limbs and hinge zones that are relatively narrow in the lower part of the carbonate section, becoming broader upsection. The form of these anticlines is best seen on the north sides of Blue Lake (Fig. S5) and 2nd Gap (Fig. S6). These folds should serve as direct analogues for the fold geometries expected in the subsurface in the middle Devonian carbonates along the eastern edge of the Liard Range (to the south).

There is a distinct jog or “step” in the main ridgeline of the Nahanni Range at both Blue Lake and 2nd Gap. These “steps,” and the coinciding presence of the folds, are features common to “displacement transfer zones” that exist at points of linkage between major thrusts. The main thrust(s) that underlie the Nahanni Range probably initiated as independent thrust surfaces that developed along strike with each other. As the amount of displacement increased on the individual thrusts, they grew in strike length until they overlapped and, eventually, merged with one another. The linkage zones between adjoining thrusts are commonly the locations where each of the connecting thrusts has its smallest offset. The associated hangingwall anticlines are physically lower in these linkage zones, and are thus more likely to be preserved from erosion here than in the central part of the thrust, where displacements can be substantially greater. Although it is common for folds to plunge past each other in displacement transfer zones, such an arrangement is not clearly expressed in the features exposed in the Blue Lake and 2nd Gap areas.

South of Blue Lake, where most of our attention was actually focused, the hinge and forelimb region of the hangingwall anticline is eroded (see Fig. S4), leaving only the planar backlimb (west limb) of the fold. The measured bedding dip at most of our measurement locations is ~25˚W. The underlying thrust(s) probably have a similar orientation. In this region south of Blue Lake there are also some minor thrusts indicated on the GSC maps of the area. On the steep eastern slope of Nahanni Ridge these small thrust are indicated by a slight divergence of bedding in the lower part of the exposed carbonate section (Fig. S7, within the Arnica Fm.) and by small folds associated with the thrusting (Fig. S8) [the axis of this fold trends 11˚ →214˚, which is quite oblique to the general N-S trend of this range]. Although these minor folds are much to small to serve as analogues to exploration targets, they do provide a good indication of the type of fracturing that exists in the fold hinge zones (see next section).

Nahanni Butte is the major topographic high in this area (Fig. S2). Structurally, it is the salient of a dome or "pericline." This structure has a moderate plunge to the south (to "Little Butte") and a steep plunge to the north. The internal structure of the Nahanni Butte salient appears to include a number of secondary thrusts and a number of major vertical silica-dolomite veins. The characteristics of the thrusts were not investigated, but the veins were examined in some detail, and discussed elsewhere in this report.

The E-W Ridge joins the northern end of the N-S trending Nahanni Butte structure (Fig. S1) to the southern end of the N-S trending Nahanni Range. The structure of the E-W Ridge (within the limits of the existing outcrop) is a very broad anticline (Fig. S3) that plunges steeply to the north (similar to the Nahanni Butte structure). Unfortunately, the existing outcrops provide no indication of the geometry of this structure to the south.

The E-W trend of the E-W Ridge, the moderately steep northerly plunge of both the E-W Ridge and Nahanni Butte structures, and the presence of many quartz-dolomite veins (commonly E-W trending) throughout these two features combine to indicate that some significant, deep-seated structure may exist here. Lacking any direct information, we speculate there is a high-angle E-W trending fault system developed in the basement here, which has had several episodes of movement and/or hydrothermal activity.

The Headless Range and Prairie Creek Anticline are both broad antiformal structures located several tens of kilometers west of the Nahanni Range and Nahanni Butte. The outcrop structure of the southern Headless Range structure consists basically of homoclinally east-dipping middle Devonian carbonates. A reverse or thrust fault is mapped on western side of the range, but we could not see direct evidence of the fault trace during our casual inspection of the area. The surface dips and the mapped fault configuration indicate that this is a west-verging structure (in contrast to the east-verging structures along the Nahanni Range). Across the Headless Range there are some minor, broad folds (Fig. S9, fold trend 14˚ →143˚) and faults evident. It is not clear if these are compressional structures associated with E-W compression or simply drape flexures developed above high-angle faults at depth. In either case, such secondary structures may also be expected to occur in analogous subsurface features in the Kotaneelee-Pointed Mtn.-LaBiche region.

The west flank of Prairie Creek Anticline is formed by a very uniformly dipping (40˚ to 50˚) panel of middle Devonian carbonates (Fig. S10 & S11). A local deflection to vertical dip (Fig. S12) is probably due to movement on a vertical fault at depth. These west-dipping beds transition to horizontal beds in the core of the structure over a rather narrow hinge zone (Figs. S13 & S14). We did not directly examine the geometry of the east flank of this fold. We noted one vertical vein of quartz(?) near the crest of this structure, a feature common in the Nahanni Range - Nahanni Butte region (see below).

Fracture systems

Fractures developed in the Manetoe facies dolostones derive from three dominant factors, viz. (1) fractures created during the hydrothermal dolomitization process, (2) fractures associated with systems of vertical dykes or veins and (3) fractures associated with the development of the "Laramide" structures in this region. These three fracture groups formed at different times, have different morphologies and generally have different associated mineral cements. The fractures associated with the HTD process and with the Laramide deformation are present, to varying degrees, throughout the area.

The HTD process created a penetrative strata-parallel openings and irregular fractures that are partially to totally infilled with dolomite cements (Figs. F1 & F2). In some locations the rock is coarsely brecciated with the HTD fractures (Figs. F3 & F4). [There have been suggestions that the strata-parallel zones of dolomite cements infilled bedding parallel fracture zones, but these zones generally do not have a fracture morphology, c.f. Figs. F1 & F2.] The void space (fracture or otherwise) in the HTD dolostones that are not infilled with dolomite (or later) cement are probably the main contributors to reservoir storage volume in the Manetoe facies.

The tectonic fractures (Laramide) are well developed throughout the area investigated, and generally occur either as hairline aperture fractures (no more than a few 10's of µm in width) without evident infilling cements (Fig. F5) or as larger aperture features (generally several 10's of µm to several mm's in width) that are completely infilled with calcite cement (Fig. F1, F2 & F6). In some cases the tectonic fractures can have apertures several cms wide (Fig. F7), but these are also calcite filled. The calcite that is infilling the larger aperture fractures can also invade and fill residual void space of the HTD (Fig. F8).

Tectonic fractures commonly develop in one, two or three distinct orientation sets at any particular outcrop location. During this field effort we collected small groups of fracture orientation data at several locations along the Nahanni Range in moderately west-dipping beds (Fig. F9). At most locations, the fracture data recorded show one dominant orientation trend, and it is generally oriented NW-SE, which is intermediate between a type I and type II trend.

At some locations the density of the tectonic fractures can be extremely high (Fig. 10) and/or a tectonic breccia can develop (Fig. 12). These strong deformation fabrics are developed in association with minor folds (Fig. S8) or fault zones (Fig. F11). If the void spaces that develop along the fractures and between the breccia are not completely infilled with cements, such zones of very intense deformation could create very good reservoir flow pathways.

In addition to the HTD and tectonic fractures, there are locations where large veins, oriented at high angles to bedding, occur (Figs. F13, F14, F15 & F16). These range from mm's to metres in width. Within the Manetoe facies dolostones, these are consistently infilled with quartz (occasionally with accessory metal-based minerals). Where these veins penetrate the Nahanni Fm. limestones, the infilling minerals are a combination of quartz and dolomite, as described elsewhere in the report.

The quartz-filled veins are clearly overprinted by tectonic fractures (Figs. F15 & F16), indicating that they developed before the Laramide deformation, or at an early stage of this deformation. The quartz-filled veins also transect the HTD fabrics (Figs. 14 & F17), indicating that they formed after the HTD event. In areas where the quartz-filled veins exist, quartz commonly invades and infills residual void space of the HTD (Fig. F18).

The quartz-filled veins are very common in the Nahanni Butte – E-W Ridge area (e.g. Fig. F15), and they have been observed at other locations along Nahanni Range and elsewhere (Fig. S13). We also observed development of veins with undetermined mineral infill at several other locations along the Nahanni Range (Fig. 19). Although most of these veins are probably quartz-filled, there are some major calcite-filled veins through the area (Fig. F20, in this case a feature with clear shear offset). Without direct inspection, it is often not possible to know whether the infilling mineral is calcite or quartz.

The quartz-filled veins are the largest "fracture" fabrics observed in the area. In some locations they are very common, but in others they are completely absent. These features may be related to a deep-seated ("basement") fault system, but we have not established this or any other genesis.

All of the fracture types that we observe either have an unfilled but extremely narrow aperture or they filled with some type of mineral cement (dolomite, quartz or calcite, in that temporal order). Regardless of their origin, the fractures can be expected to serve as conduits in a reservoir situation only to the extent that they are not completely infilled with cements. In many cases it appears that the crystals growing in from either wall of the fracture (or from the walls of the HTD vugs) do not completely grow together. In terms of potential reservoir contribution, the factors affecting the cementation in the fractures are as important as the factors controlling their formation and distribution.

FAULT & BRECCIA DISTRIBUTION (Chris Bergquist)

1. ***Nahanni Butte Interpreted Crestal Montage***

*Field Note Observations: C. Bergquist & M. Marshall (**RED**=Key Observation)*

NB SITE 1 N61d 05m 11.6s W123d 22m 58.1s

Fault zone and small "quarry" below hut. 1m wide calcite/quartz zone, extending to 3m wide with smaller fracture swarm showing black silicified fossils. Strike = 120d, Dip = 80dN. Silica zone 3 feet wide. **Massive 2' x 5' chasm with quartz crystal lining, then 3"-5" dolomite rhombs growing into the quartz crystals. Clearly silica first, quartz crystals second, dolomite rhombs third**. Secondary significant fracture @ Strike = 50d, Dip = 75d SE. Other mineralization to the North, 10m wide.

NB SITE 2 N61d 05m 11.7s W123d 23m 04.8s

Small collapse feature with 20m wide altered zones, large vugs showing silica replacement and dolomite as per site 1. **Dilation and reidel fractures**. Strike = 110d, Dip = 80dS. Fossiliferous matrix with amphipora, corals, and thamnapora. Strongly bioturbated**.** **Silicified fossils with fracture-enlarged vugs (incomplete silica replacement). On North fringe zone ~2m out host rock is partially dolomitized.** Unmineralized fracture set with Strike = 20d. Large karst hole at downslope portion of zone.

NB SITE 3

Silicified fractures in limestone with Strike = 130d, Dip = 75dN. **Fossiliferous and bioturbated. Mottled gray & pink partially dolomitized host rock. 50m SW have fractured limestone, ~20% dolomite**. Black silica in horizontal enlarged vugs within a highly fossiliferous zone.

NB SITE 4

Large "quarry" on slope below 3 above. Eastern edge contains 3-4m wide massive silica fault zone as above. **Silica highly fractured, with replacement of prior zebra dolomite texture in part.** Mineralized zone has Strike = 124d, Dip = 74dN. **Unmineralized fractures cut mineralized zone ~every 30cm**, with Strike = 45d, Dip = 66dSE. To far eastern edge of quarry (40m) shows quartz-filled fractures every 2-5m, with Strike = 110d, Dip = 85dS. **Within silica zone have incomplete silica occlusion and replacement of host rock, with scattered later dissolution. Huge vugs lined with silica & quartz, then dolomite. Partial to complete dolomitization of matrix in zone. Mottled dolomites mostly ~50% dolomite**. Large sinkhole at base of quarry. Silica rubble zone with unique, green-colored lichen 3-4m wide, the same as actual outcrop. 50m NW have ~2m wide silica zone as above. Massive vugs with silica rind, quartz and dolomite fillings. Blocks and smaller bits breaking off into the voids between silica veins. **1-2m away from silica ~50-60% dolomite in host rock. 0-50m NW small vertical fractures, horizontal dolomite in ~80% along solution vugs**. Appears like early stage zebra texture. 25m NW another 2-3m wide silica zone. At far NW edge of quarry a silica-filled fracture zone, 3-4' wide with Strike = 135d, Dip = 90d. Total 150m wide fracture zone with multiple small fractures between. **Black silica in fractures and fossils, merging to black dolomite away from silica veins**. Mottled dolomite in fracture zone.

NB SITE 5

Corner of "quarry" at creek. Calcite-filled fractures in fossiliferous Nahanni limestone, Strike = 130d. 'White' creek bed is exposed limestone with 10-20% dolomite. Multiple fracture sets in creek bed. Mineralized and dolomite (?) filled are two sets: Strike = 160d & 80d (same as creek bed). Open, unmineralized fractures: Strike = 135d & 64d. **SW edge of quarry is a massive 3.5m wide silica vein. Strike = 140d, dolomite (?) rhombic crystals inside quartz-lined vugs**. To the South the zone increases to a 8-10m wide mineralized zone.

NB SITE 6

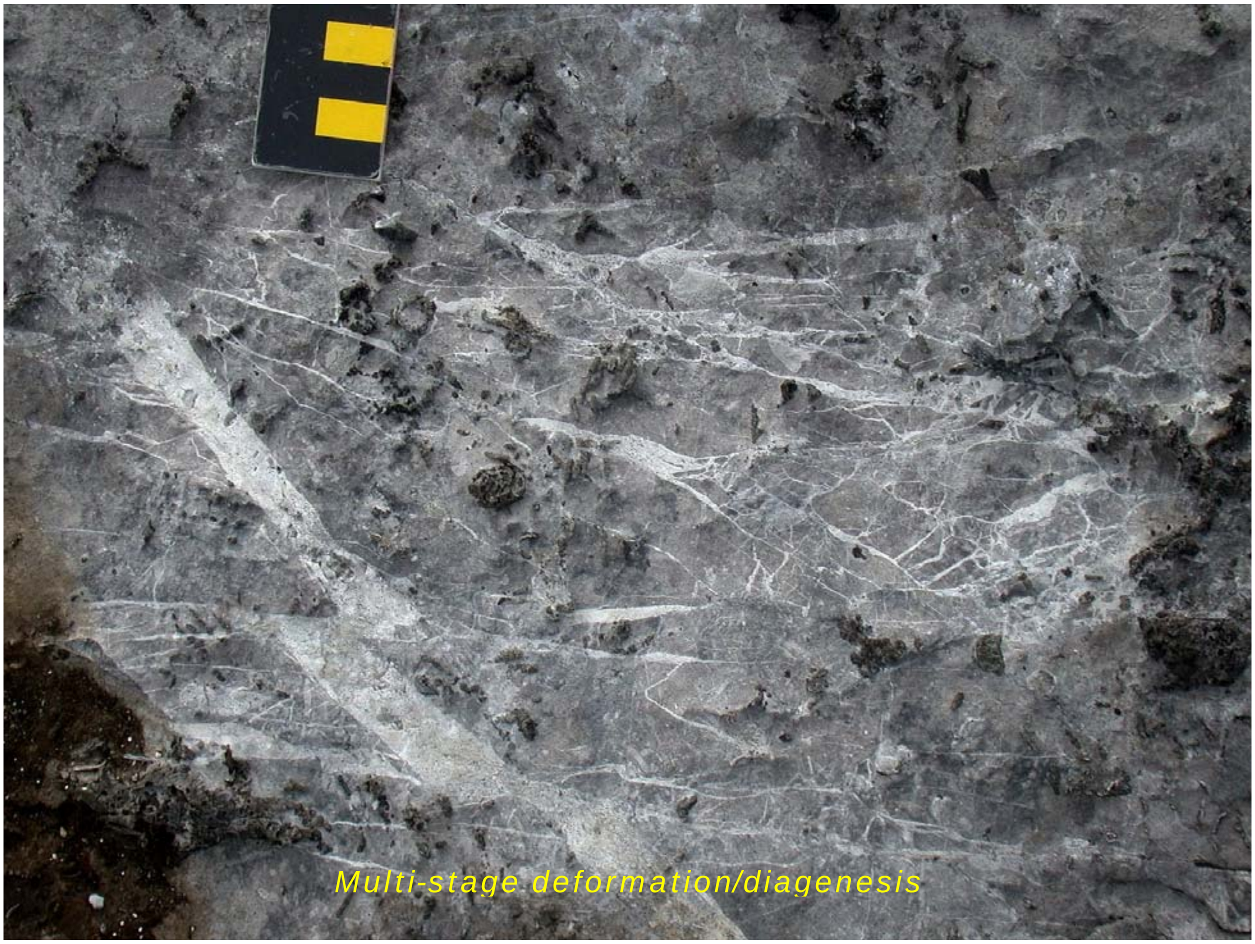
Flat face before the second 'bump-out'. Continuation of mineralized fault zone with Strike = 130d. **Sub-horizontal zones filled with zebra-type saddle dolomite lined with black silica/ dolomite. Matrix host rock is mottled dolomite, heavily fractured zone. At third 'bump-out' have massive thamnapora coral beds. Corals dense, 1.5-2m thick in limestone ~20m NW of silicified zone**. Silica zone here 2m wide, massive with a 3m mottled dolomite zone surrounding it.

NB SITE 7

NW end of "quarry", mineralized fault, Strike = 135d. **Mottled dolomite in fossiliferous zone. Cherty black silica in sub-horizontal layers, up to 6" stroms replaced in altered zones.**

NB SITE 8

Breccia zone along "Marc's" silica fault zone. Strike ~130d. **Main fault splinters into a tectonic breccia.** Strike = 135d, Dip = 85dN into the left gully.



NB SITE 9

Silica zone as a continuation from the previous gully, Strike = 150d, Dip = 85dN. Zone 1m wide increasing to 2.5m in an overall +-10m zone with other small, mineralized fractures of faults. Strike = 150d, Dip = 75dN in a mineralized small fault. **At the cliff's crest Strike = 125d have a mineralized zone with dilation fractures indicating a right lateral shear system**. Second small gully running Strike = 85d, with platy dolomite and silica boulders. Continues south into the cliff face. N61d 04m 59.6 by W123d 23m 05.6s: Fault trend with silica replacing all. **Dolomite massive, then silica rind. Strike trend cuts off cliff faces. QUESTION: Old basement fault trend?** N61d 04m 59.6s by W123d 23m 09.4s: Silica & dolomite-filled fault zone. Strike = 85d, Dip = 85dN

NB SITE 10

Silica train Strike = 110d. **Zone platy dolomite in dense cryptocrystalline dolomite, recessive canyon**. Quartz & silica spire to the North side with Strike = 130d. 150m North have mineralized silica zone with fractured limestone, Strike = 140d. ~500m NE have "valley" with two small mineralized fault zones: Strikes = 140d & 165d. N61d 05m 04.1s by W123d 22m 58.1s: Near "fault" intersect with cliff top, area of increasing black silica replacement of fossils in limestone. Very highly fractured rubble zone. Dk gry, fossiliferous limestone, fractured with lt gy calcite in fractures providing overall "collapse" appearance. **High proportion of fossil silica replacement. 20m side cliff face with extensive, ~60% rubblization, preferentially in horizontal layers alternating with massive limestone. Rubble created by extensive horizontal (1) and sub-vertical (2) fractures. When extensive, gives appearance of collapse breccia. QUESTION: Is this an early/marginal phase of a collapse breccia?** N61d 05m 02.8s by W123d 23m 01.0s: Elevation 1380m @ notch in cliff top. 10m wide cleft between limestone rubble host rock walls. ~2-3m wide dolomite & silica zone down center, primarily in float rubble and up to 2m diameter blocks. **Dolomitized host rock with saddle dolomite lining cavities and fractures. Massive silica replacement of dolomite host in core of blocks, coated by up to 2" layer of crystalline quartz.**

NB SITE 11

Two massive silica fault zones @ East end of valley. **Mottled dolomite to the West**. Zones are 6m and 12m in width, Strike = 175d. **These are the dark band at top of cliff seen from the South, in the area of the fault offset**. The zones line up with a "dark band" at the base of the far southern, lower cliff face. Zone consists of solid white, coarsely crystalline quartz. Dip appears at the base to be about ~70dSE. Massive scree pile to the east below where these zones form ridge proceeding downslope.

NB SITE 12

2m wide silica zone, Strike = 165d. Small zone in limestone, Strike = 110d, Dip = 80dW. 50m East find a 2-3m wide silica zone similar to Sites 1-10. The silica zone forms a resistant hilltop. **Hot spring, currently inactive from the upper part of the slope in the silica zone**. Host rock beds more steeply dipping, now at ~50dE.

NB SITE 13

Major fault zone with 2-3m wide massive silica zone plus some dolomite. Forms cliff face, minor slickenslides striking downslope. Zone Strike = 170d. Bed Dip = 42dE. Over a 200m interval towards the East run into another 3m wide breccia zone midway. Breccia zone contains massive dolomite rhombs. **Sequence of limestone matrix, dolomitization of matrix, silification of zones along faults or fractures, silica crystal lining of void spaces, dolomite rhomb infilling of remaining void space, ???calcite druse and final infilling of porosity.**

NB SITE 14

25-30m silica zone, complexly twisted and deformed.

NB SITE 15

Fault zone. Strike = 165d to 140d leading to lower knob. Silicified platy dolomite (possible Headless Fm?) as seen elsewhere on the top of the dome. East edge of zone have a silica-filled fracture swarm, Strike = 135d, Dip = 85dW, in limestone host rock. Can see a massive ~4m wide silica zone in cliff along strike. 20m eastwards find a 2m wide silica zone with Strike = 135d.

NB SITE 16

Three photo panorama showing 5 silica zones across slope. West to East have 4m wide zone with Strike = 135d, 8m wide zone with Strike = 110d, 6m zone with Strike = 115d (Site 17). **Zones are massive silica, heavily brecciated. Slickenslides with 110d strike found in breccia zone associated with zone two. At the intersection of the first two zones the alteration and mineralization is significantly greater than elsewhere**.

NB SITE 17

6m wide silica zone with Strike = 115d. Across small eroded low another 10m wide and Strike = 150d. Predominately silica with some dolomite to the SW. **Highly fractured**.

NB SITE 18

~235m wide silica zone with **Strike = 10d, aligning with river offsets to the North**. As one proceeds eastwards find numerous silica mega breccias and silica zones: Mega breccia at east end of "quartz ridge" 30-40m wide, limestone blocks, silica and quartz, vugs infilled with quartz, blocks up to 2m diameter. Mega breccias ~60% quartz. Towards the east 100m limestone, 25m wide silica zone Strike = 170d, limestone 'raft', 15m silica zone Strike = 135d, 75m limestone, 150m+ silica zone Strike ~155d, ~50m limestone, further massive silica ridge at far end of outcrop. **From the air this clearly extends the length of the ridge and is a massive silica fault? Zone**.

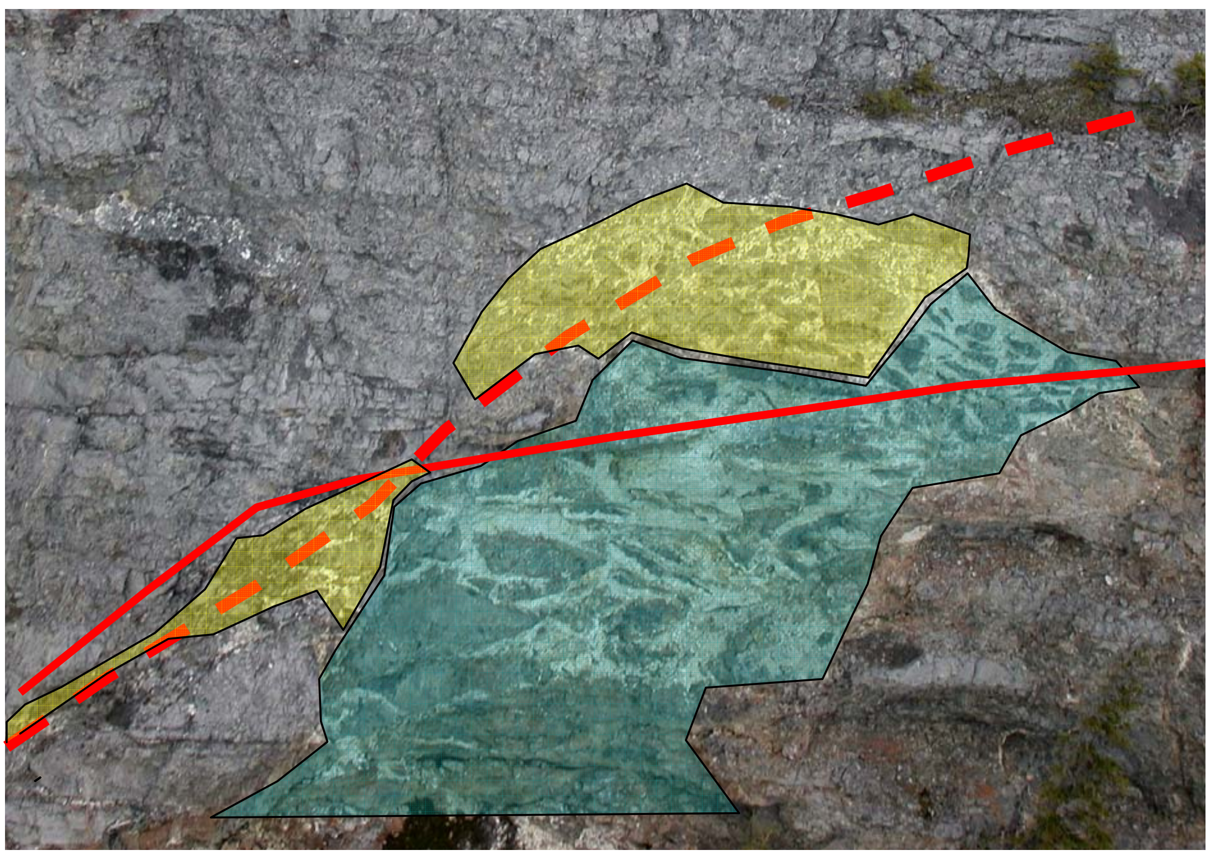
*2. **Nahanni Butte Interpreted South Cliff-Face***

Observations:

Outcrop field stations as shown. All interpretations from images, field checking only completed on Butte crest. Primary lateral ramp overthrust cuts silica zone in center of montage, though not clearly consistent with silica zone with depth. Secondary lateral ramp overthrust to the east (right), a severely silicified zone as well. Demonstrated high density of small thrusts and backthrusts in zone between two primary lateral ramp thrusts.

Dolomite & Silica: branching upward through complete carbonate section. Fault-aligned along 'basement' trend. Laramide faults crosscut at later date…


Collapse breccia overlying "feeder" fracture swarm



3. ***<u>Nahanni Butte Fault & Breccia Detail</u>***

Observations:

A significant portion of the Butte's cliff-face is covered with slump debris so a clear picture of breccia distribution is not possible. In exposures there is a smattering of breccias across all zones, with most located within the uppermost Nahanni limestones. Breccia zones up to +-200m height and where sub-horizontal bedding-confined zones break upwards into overlying beds. Breccia zones commonly associated with faulting or severe fracturation.

Zones appear to be predominately "grain-supported" host rock blocks in tectonically brecciated zones, occasionally with "collapse" features. White infill up to 25% breccia volume assumed to be large dolomite rhombs that are exposed on the ridge crest.

Several breccias show very clear offset by type 3 sub-horizontal Laramide faults and fractures, indicating pre-existance of brecciation. Silicification of breccia and or fault zones not apparent over most of outcrop area, as ii is in the better exposures on the EW Ridge. Clear increase in silica zones towards east end of Butte, and in Nahanni limestone breccia zones at the top of the outcrop. Appears to be a strong correlation of major silica zones to faults, though cliff-face interpretation of easternmost silica via photos alone.

4. ***<u>EW Ridge Interpreted Crestal Mosaic</u>***

Field Note Observations: C. Bergquist & A. Anastasis (***RED***=*Key Observation)*

EWR SITE 1

Start point, helicopter drop-off at ridge crest. Small silica fault zone, continuing intermittently down slope to the north. Strike = ?

EWR SITE 2

Fracture breccia in ls Nahanni host rock.

EWR SITE 3

Silica fault zone with dolomite infill on west edge of 'quarry'. Alexis' photos. Strike = ? **On southern cliff face see uppermost 10-12' of Nahanni as massive and continuous underlain by 10-15' of collapse breccia including large host rock blocks and intervening dolomite (?) rhomb infill. Appears to extend horizontally a minimum of 20-30m**. Need to check southern cliff photos.

EWR SITE 4

Small silica fault zone. Strike = ?

EWR SITE 5

Silica fault zone. Strike = ?

EWR SITE 6

Coalesced small oval silica "mounds" at ridge-crest. Poorly developed linear extension down slope to the north.

EWR SITE 7

Dolomite "vent" in zone of collapse breccia, 9" wide vent with 3' solid saddle dolomite walls and 3' cave, 3m wide ls blocks in breccia plus massive saddle dolomite along ridge top above "quarry. Silica fault zone on west edge quarry, Strike = 150.

EWR SITE 8

West edge quarry walls part of massive collapse breccia. **Breccia consisting of ls and partially-dolomitized host rock blocks to several meters and massive large rhomb saddle dolomite in "matrix" and occasional silica "rind" blocks encased in breccia. Walls generally saddle dolomite with no silica rind**.

EWR SITE 9

East edge collapse breccia contains massive host rock blocks up to 5m in length. Has appearance of in place matrix with saddle dolomite zones extending into "host" rock gradationally. Collapse breccia continuous 150-200m across the gully and extending 300-500m downslope where quarry extends, as well as upslope to ridge crest.

EWR SITE 10

Extensive silica knobs with saddle dolomite along ridge crest, about 3-4 smaller zones over ~100m.

EWR SITE 11

Same as 10 above. **Forms resistant knobs along ridge crest above slumped crest**. Lower section was not viewed due to helicopter pickup.

EWR SITE 12

Silica knobs at ridge crest.

EWR SITE 13

Several collapse breccia knobs with silica, quartz and saddle dolomite, and karst hole at ridge crest. Silica fault zone with Strike = 170 extending downslope.

EWR SITE 14

Silica fault zone along flank of small ridge. Strike = 170 extending downslope.

EWR SITE 15

Open fracture set on flat exposed ls host rock. Three Strikes = 25, 90 & 155 degrees. Most extensive is 155.

EWR SITE 16

Very small fracture with quartz crystal lining.

EWR SITE 17

Two small silica quartz fracture zones extending downslope on both east and west edges of collapsed "quarry". No specific collapse breccia noted in quarry zone, except zones of dolomite-filled (?) fractures and partial dolomitization.

EWR SITE 18

Oval pod of silica-rimmed collapse breccia approximately 10m x 25m dimension. Clear silica rind, then quartz crystal and interior saddle dolomite. About 50m east along ridge have small pod of same ~2x5m with silica fault zone extending downslope at Strike = 10 degrees.

EWR SITE 19

Downslope and east of site 18. **Another "quarry" with fractured and slumped ls blocks. Intense shattering along horizontal layers. Rare dolomite rhomb infills, fractures dolomite-filled. Mottled partially dolomitized host rock. No visible collapse breccia.**

EWR SITE 20

Fracture breccia in downslope quarry area. Single small silica fault zone in heart of zone trending downslope.

EWR SITE 21

Major collapse breccia with large amounts of coarse crystalline rhombic saddle dolomite. A bit gradational to east with large host rock blocks. Extensive to the west.

EWR SITE 22

Silica & dolomite ribs leading into heart of collapse breccia zone. Breccia also along ridge crest along with a significant karst hole. Strike =?

EWR SITE 23

Well-developed collapse breccia. Along upper part of ridge and along crest.

EWR SITE 24

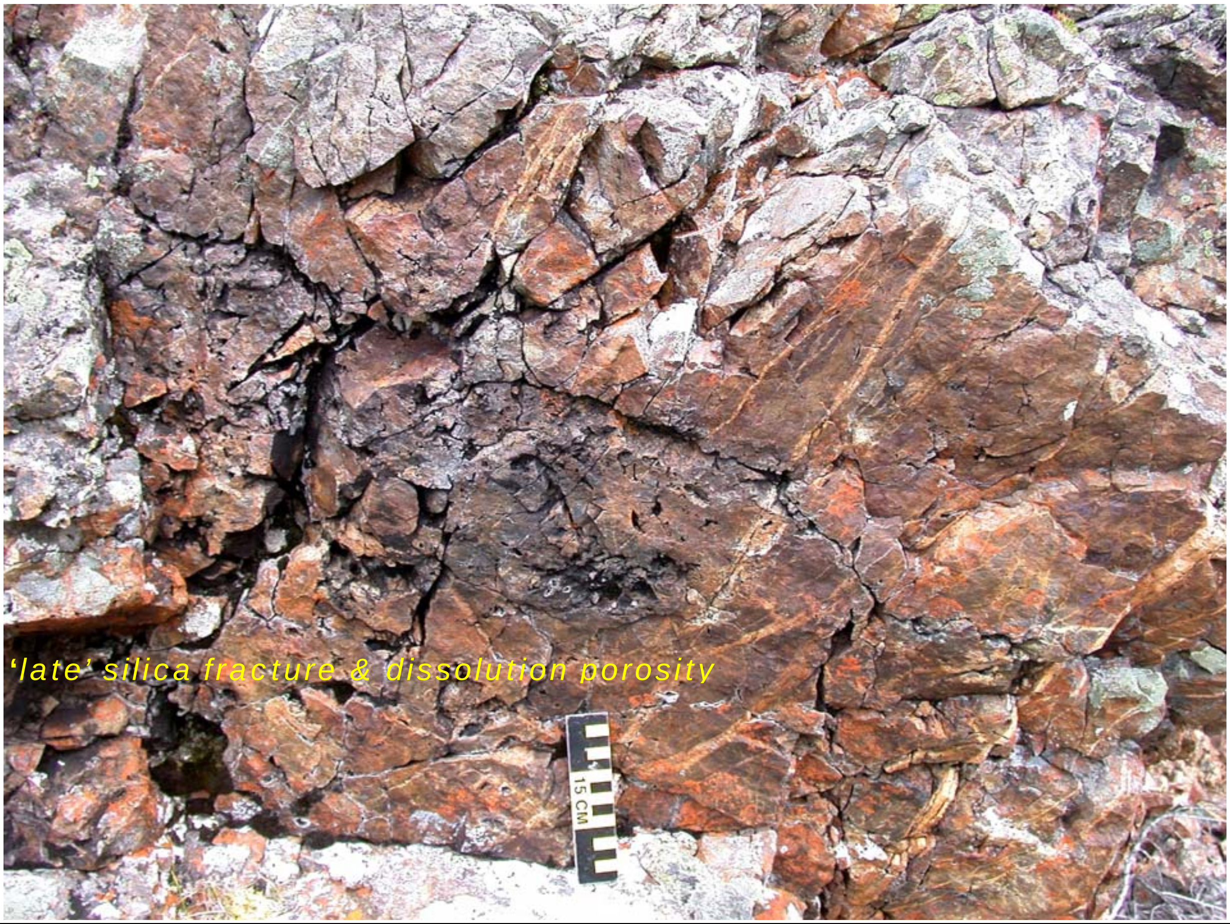
Continuous collapse breccia, transitional at western margin to a fracture breccia, but with occasional saddle dolomite still present. Saddle dolomite in outcrop to within 2m of silica fault swarm.

EWR SITE 25

There is a total of ~60m wide silica fault swarm at ridge crest, similar to eastern Nahanni Butte. On southern cliff face have single ~1m wide zone at base which splits into 6 zones at crest. Silica is exposed along whole length, and massive at crest with replacement of host rock there. Silica rind is transitional to dolomite over ~1m zone. "Brucite" (?) and Malachite (?) present coating all surfaces in heart of vein, after both the quartz and the dolomite.

EWR SITE 26

Joint set in the silica and dolomite zones, post-dating emplacement. Strike =?



EWR SITE 27

Continuous outcrop in cliffs on downslope edge of silica 'dike' swarm. **Main silica 'dike', large vugs filled with silica and saddle dolomite as in the western area of Nahanni Butte. Other vugs filled with silica and qtz crystals but no dolomite. Brucite & malachite coatings on all. . Sequence is clearly silica, quartz crystals and dolomite, although dolomite may not always be present. Perhaps missing when silica occludes all pore space or no access into heart of vug? Current porosity in silicified host rock within fractures, fossils and styolites, indicating late movement**. Strike = 130 in the porous zone. **At outer contact come into presence of black silica fractures and fossils in the host dolomite as is seen extensively elsewhere. An example would be the ridge crest on N-S ridge where I first saw the manatoe zebra dolomites. Same silicification front (partial) 4m above last of the zebra dolomites. This alteration zone continues outwards from the silica for 4-5m, and the collapse breccia starts 1-2m beyond that**.


1a/ Matrix dolomite,
1b/ Dolomite rhombs(basement trend),
2a/ Massive silica(basement trend),
2b/ Euhedral quartz(basement trend),
3/ Dolomite rhombs,
4/ Fracture porosity(Laramide),
5/ Calcite veins & druse(post-Laramide)


Isolated porosity in replacive silica

5. <u>EW Ridge Interpreted Southern Face</u>

Observations:

Structure is a double-plunging anticline broken into approximate thirds between the Nahanni, Landry and Arnica formations. Thin Headless shale break between the Nahanni & Landry could be lower but is picked at present position based on the significant barrier to breccia and dolomitization shown below the current pick. Overall section cut by a number of type 3 sub-horizontal fault planes the gradually cut up section along the outcrop. EW displacement is in the order of meters to tens of meters, with movement generally towards the East. Faults frequently associated with vertical breccia zones. Fracturing is extensive, especially in the lower Arnica and Landry intervals. Breccia intervals located predominately along horizontal and sub-horizontal zones of bedding. There are several areas where breccias “chimneys” climb through the section into the Nahanni. These breccia “pipes” appear to be related to structure and extend into the section up to a km, based on crestal outcrop data. The majority of the breccias are located within the Landry Formation where ~ 20-35% of the section is brecciated. The overlying Nahanni is 5-10% brecciated and the underlying Arnica is 10-25% brecciated, but rarely outside a single bedding layer. Lighter coloration of the outcrop face is assumed to represent Manatoe facies development of saddle dolomites. This was confirmed in the Landry outcrops to the far west of the face, and to the north along the NS Range. As seen, this is focused almost exclusively within the Landry, although it is seen in isolated pockets within the Nahanni and isolated layers within the Arnica. Silica on the EW Ridge appears to be isolated to fault zones where it has replaced previous fabrics, and is seen by nature of its rusty weathering color in outcrop. Silica is concentrated from the crest and westwards-towards Nahanni Butte-with the largest zone on the far western end of the outcrop. Silica does not seem to be tied to the late type Laramide faulting but is clearly cut by it, as seen by the offset of the zone to the west.

6. EW Ridge Silica, Breccia & Fault Detail

Observations:

Silica shown is the major silica zone to the far west of the overall EW Ridge. Silica zone is clearly offset by the type 3 faults cutting it at several levels, with horizontal displacements of several 10's of meters towards the east. Silica appears to have moved vertically along a pre-existing fault zone flaring into numerous fingers near the top of the Nahanni. Some relationship of silica zone(s) with dolomite breccias, especially where the rusty-weathering silica seems to have rimmed and replaced pre-existing breccia. A similar relationship is seen along the crestal outcrops. Both may be related to an early phase of structuring cutting the section near-vertically.

7. EW Ridge South-Facing Breccia Complexes

Observations:

Several breccias, which demonstrate both Laramide fault offset and variation in breccia type. Breccias vary from fractured host rock limestone to cave collapse and infill. They appear to be predominately clast-supported with dolomite rhomb infill of open fractures and pore space. Small scale <5m offset fractures, thrusts and back-thrusts frequently cut the breccia zones. The best-developed breccia zone appears to climb through the section, as well as tie to a major collapse feature in the crestal outcrop (site 3).

NS NAHANNI RANGE

Site 1 (not shown on montage or map)

Field Note Observations: C. Bergquist & M. Marshall *(**RED**=Key Observation)*

Ridge top saddle ~6km north of EW Ridge (Jamie & Alexis pickup, field day 2). Limestone at crest of ridge south of saddle, probable Nahanni Fm. **Manatoe dolomite ~10m lower in section in probable Landry. Manatoe consists of pervasive zebra dolomites. 3m interval below base of last limestone and top zebra dolomites. At 4m above Manatoe dolomite show partial black silica replacement of fossils**. Headless fm very thin <2m thickness and poorly defined in outcrop, nonetheless separating Nahanni limestone from underlying Landry dolomites of the Manatoe facies.

8. Map View Interpretation

Observations:

Silica zones highlighted in red on aerial photo demonstrate strong and consistent orientation to the SE. Strike of silica zones ranges from 110-175d with dips near vertical, generally >70. Alignment strongly parallels a Proterozoic basement rift trend of ~150d seen nearby to the SE in high-resolution magnetics data. Other trends shown in yellow are variable, with the primary trends ~EW and to a lesser extent conjugate sets at 135d and 45d. The EW trend of faults/fractures represents a type 1 fracture trend, paralleling the direction of Laramide-aged thrusting. Shown in dashed black are three to four stages of over-thrusting along the southern margin of a major lateral ramp. Lateral ramp borders major right-lateral tear fault displacement of Liard and Nahanni Ranges, with displacement zone trending ~NW direction up along South Nahanni river. It is postulated that the localized over-thrusting progressed from west to east over time and represents a fanning of the lateral ramp thrusts to the east until merged with the primary NS Range thrust sheet.

Field Work Summary