

The Colors of the Sheltie: The New DNA Findings

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ε [A series \(Agouti\)](#)

ε [M Series \(Merle\)](#)

ε [S series \(Spotting and White Markings\)](#)

ε [D series \(Gray Dilution, Blue Dilution\)](#)

ε [T series \(Ticking\)](#)

ε [B series \(Brown/Liver/Chocolate\)](#)

ε [C series \(Chinchilla, Albino\)](#)

ε [E series \(Extension\)](#)

ε [G series \(Progressive Graying\)](#)

ε [H series \(Harlequin\)](#)

ε [K series \(Dominant Black, Brindle, Tan\)](#)

Knowledge of canine color genetics has come a long way since Clarence Little first published “The Inheritance of Coat Color in Dogs” in 1957. In the past few years, color inheritance has been studied in many species at the DNA level, and the specific genes involved have been identified. Many of Little’s theories of color inheritance have been confirmed, a few have been discredited, and some problem colors that didn’t fit known inheritance patterns have been explained.

This page does not describe how to figure expected colors for any given litter. Numerous other sources do that very well, and several of those are listed below. This article does relate breeders’ practical knowledge of Sheltie color inheritance to the recent findings about the DNA changes that lead to these colors. Because science is a process, and color genetics is work in progress, future research may well modify some of what now appears to be fact.

The Language of Color Inheritance:

DNA, or deoxyribonucleic acid is the basis of inheritance. It is a chemical composed of double chains of nucleotides. **Nucleotides** are composed of deoxyribose (a sugar), phosphate (phosphoric acid) and one of four nitrogen-containing bases. A set of three bases codes for a particular amino acid. Proteins are built of chains of amino acids added in sequence, as coded by a particular sequence of nucleotides.

Chromosomes are double chains of DNA in the nucleus of cells. Chromosomes come in pairs, with the exception of the X and Y chromosomes in the male, which determine sex. A dog has 36 pairs of chromosomes.

Genes are sequences of DNA on chromosomes that lead to specific inherited characteristics, usually by coding particular proteins. **Alleles** are variants of the same gene. Since chromosomes come in pairs, only two alleles can be present in any given animal. However, there can be more than two alleles in a population of animals, and more than one mutation in each allele.

Homozygous is the condition in which both alleles are identical, such as in a pure-for-sable or in a double merle Sheltie. **Heterozygous** is the condition in which both alleles are not identical, such as in a tri-factored sable.

Genotype refers to the DNA alleles that are present in the dog. **Phenotype** refers to what the dog looks like.

Dominant alleles are those which are expressed even if only one copy of the allele is present. The appearance of the dog is the same whether the dog is homozygous or heterozygous. An example of this is the sable coat color. **Recessive** alleles are those that are expressed only when two copies of the allele are present. For example, bicolor is recessive. When more than two alleles are present in a breed, there is a sequence of dominance. Sable is dominant over tricolor and bicolor. Tricolor is recessive to sable and dominant over bicolor. Bicolor black is recessive to both sable and tricolor. **Co-dominant or Incompletely Dominant** alleles are those in which the heterozygous condition is visibly different from either homozygote. Merle alleles can be considered co-dominant.

Epistatic and **hypostatic** are terms describing the interaction between two different genes. An epistatic gene or allele can mask the expression of the alleles of a different gene. The homozygous recessive **E** series allele, **ee**, which causes the yellow/tan coat color of Labrador Retrievers, is epistatic to the **A** series (sable, tricolor, bicolor) gene, because **ee** hides the expression of any **A** series colors. A hypostatic gene or allele can be masked by the alleles of a different gene. The **A** series gene is hypostatic to the dominant black **K^B** allele, because the **K^B** dominant black hides the expression of all **A** series genotypes.

Melanin is the pigment that we see as coat and skin color. **Melanocytes** are the cells that produce the pigment. **Eumelanin** is black or brown melanin, either of which can be diluted to gray or Isabella, or mottled to merle or harlequin. **Phaeomelanin** is yellow/tan melanin, which can be diluted to cream, or deepened to red. Sable is phaeomelanin hair, usually with some eumelanin tips and some eumelanin hair mixed in.

Color Genetics References:

On The Web:

- ⌘ [Genetics of Coat Color and Type in Dogs](#), Sheila M. Schmutz, Ph.D., Professor, Department of Animal and Poultry Science, College of Agriculture and Bioresources, University of Saskatchewan. *A comprehensive current website by a major researcher of dog coat color, with a page devoted to Sheltie colors.*
- ⌘ [Sheltie Coat Color Inheritance Calculator](#), Sparkshire Shetland Sheepdogs. *Depending on your screen resolution, you may have to zoom the size of the display to be able to use the calculator.*
- ⌘ [The Colors Of The Sheltie](#), Shetland Sheepdog Club of Northern California.

Expected Coat Color Charts:

- ⌘ **Color Inheritance Charts**, Jan & Peggy Haderlie, 1983, Los Osos, CA: Sheltie International.
- ⌘ **Sheltie Talk**, 2nd edition, Betty Jo McKinney & Barbara Rieseberg, 1985, Loveland, CO: Alpine Publications.

General Color Genetics:

- ⌘ **Burns Marca and Frazer Margaret. 1966.** Genetics of the Dog The Basis of Successful Breeding (2nd Ed). Great Britain, Oliver & Boyd Ltd. U.S., J.P Lippincott Company. *This long out of print book is a treasure if you can get hold of it.*
 - ⌘ **Little Clarence C. 1957.** The inheritance of coat color in dogs (Ithaca, N.Y.: Comstock) (reprinted by Howell Book House, New York, NY). *The classic book on dog color inheritance.*
 - ⌘ **Schmutz SM, Berryere TG. 2007.** [Genes affecting coat colour and pattern in domestic dogs. Anim Genet. 38:539-549.](#) *A journal article that reviews the genes that have been identified as affecting coat color and pattern.*
 - ⌘ **Willis, Malcolm B. 1989.** Genetics of the Dog. N.Y. Howell Book House. *A more recent and very thorough book on dog genetics, but still one that predates DNA research.*
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Major Sheltie Color Genes:

A series (Agouti)

Where: Canine chromosome 24

Gene: ASIP (agouti signal protein)

Alleles: a^y , a^w , a^t , a

In Shelties:

- ⌘ $a^y a^y$ – pure for sable
- ⌘ $a^y a^t$ – tri-factored sable
- ⌘ $a^y a$ – bi-factored sable
- ⌘ $a^t a^t$ – tricolor
- ⌘ $a^t a$ – bi-factored tricolor
- ⌘ aa – bicolor black

How It Works:

The agouti series gene controls the amount and distribution of phaeomelanin (yellow/tan) pigment in the coat, by regulating a switch between eumelanin black and phaeomelanin tan either during the growth of an individual hair or on different parts of the body.

The wild type a^w , also called wolf sable, which is not found in Shelties, results in hairs with alternating bands of black and yellow/tan. It is the original color produced in dogs by the agouti gene, but is recessive to a^y fawn/sable in breeds where both occur.

The dominant a^y allele (sable, called fawn in many breeds) produces tan hairs on all pigmented areas of the body, with varying amounts of black, banded and black-tipped hair mixed in.

The a^t allele (black and tan, tricolor) is recessive to a^y sable, but dominant over a bicolor. It restricts tan to the ventral or lower surfaces of the body—lower legs, chest, undersides and foreface.

The recessive non-agouti **a** allele (black, black and white) prevents any yellow/tan from being expressed anywhere in the coat.



Figure 1. Tricolor (left) is dominant over bicolor (right), but is recessive to sable.

At The DNA Level:

The **a^y** sables have two differences in the DNA of the agouti gene from tricolors, bicolors and in other breeds, the wild type. These changes result in the replacement of the amino acid alanine with serine (A82S) and of arginine with histidine (R83H) at two positions in the making of the Agouti signal protein.

The **a^t** allele, in the absence of **a^y**, results in tricolor or black with tan points. The tricolor and bicolor Shelties have a mutation, which consists of a duplicate segment of DNA inserted in reverse orientation into the gene. This inserted DNA is called a short interspersed nuclear element or SINE element, one of a number of transposable DNA elements that can copy and paste themselves into various positions on chromosomes. This particular SINE insertion is lacking in the **a^y** sable genotype and, in other breeds, is lacking in the **a^w** wild type genotype.

The recessive **a** bicolor allele was unknown to Clarence Little, although he suspected the existence of a recessive black. The bicolor has a mutation at a different location on the agouti gene, which results in the replacement of an arginine amino acid with cysteine (R96C). This mutation is only present in Shelties who would otherwise be tri-factored sables or tricolors.



Figure 2: Sables vary in the number of black, black-tipped and banded hairs in their coats.

Gene Interactions:

The **M** series merle gene acts on the black pigment in all the **A** series phenotypes to produce sable merles, blue merles and bicolor blue merles (bi-blues).

Dominant black, formerly called **A**, has not been found on the agouti gene. Instead, dominant black has been identified in the recently described **K** series gene, and is called **K^B**.

Cautions and Comparisons:

In the scientific literature and in many other breeds, fawn is the term used for what Sheltie fanciers call sable. The **a^w** wild type, not present in Shelties, is referred to as wolf sable.

At this time, there is no scientific evidence to support the belief that a heavily shaded sable must be tri- or bi-factored. Look at the photographs in Figure 3 and see if you can tell which dogs are pure for sable.

The use of the term bicolor to refer to black and white dogs is a fairly recent one. In earlier publications

bicolor meant the black and tan pattern, which makes perfect sense in dogs with no white markings. Libby Babin's (Babinette Shelties) articles, published in the early 1970s, clearly discuss bicolor as the black and tan pattern.

Health Concerns:

None known.

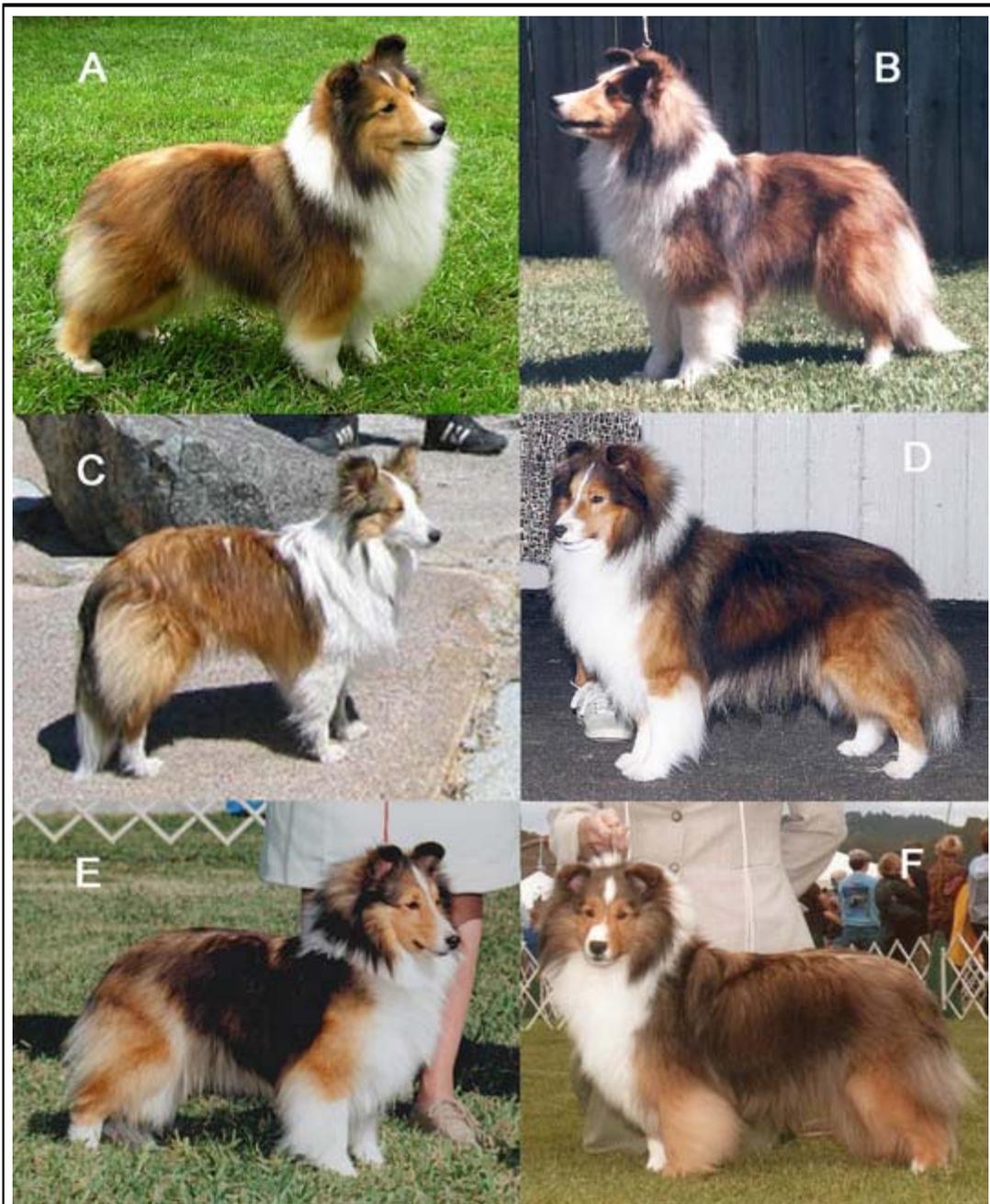


Figure 3: The dominant sable can result in different shades of tan and widely varying amounts of black in the coats. The amount of black in the coat is unreliable as a means of determining whether the dog is tri- or bifactored. Can you guess which of these Shelties are tri-factored? [The answers are at the end of this article.](#)

A Series References:

- ⌘ **Berryere TG, Kerns JA, Barsh GS, Schmutz SM. 2005.** Association of an Agouti allele with fawn or sable coat color in domestic dogs. *Mamm Genome*. 16: 262-272.
- ⌘ **Campolini R, Cecchi F, Spaterna A and Bremante A. 2012.** [Characterization of different 5'-untranslated exons of the ASIP gene in Black-and-tan Doberman Pinscher and brindle Boxer dogs. *Animal Genetics* 24 APR 2012 | DOI: 10.1111/j.1365-2052.2012.02364.x](#)
- ⌘ **Dreger DL, Schmutz SM, 2011,** [A SINE Insertion Causes the Black-and-Tan and Saddle Tan Phenotypes in Domestic Dogs. *J Hered* 102. 11-18.](#)

- ⌘ **Kerns JA, Newton J, Berryere TG, Rubin EM, Cheng J-F, et al. 2004.** Characterization of the dog Agouti gene and identification of a nonagouti mutation in German Shepherd Dogs. *Mamm Genome* 15, 798-808.
- ⌘ [Kerns JA, Olivier M, Lust G, Barsh GS. 2003. Exclusion of melanocortin-1 receptor \(Mc1r\) and agouti as candidates for dominant black in dogs. *J Hered* 94, 75-79.](#)
- ⌘ [Oguro-Okana M, Honda M, Yamazaki K and Okano K. 2011. Mutations in the Melanocortin 1 Receptor, \$\beta\$ -Defensin103 and Agouti Signaling Protein Genes, Their Association with Coat Color Phenotypes in Akita-Inu Dogs. *Journal of Veterinary Medical Science* 73, 853-858.](#)

M series (Merle)

Where: Canine chromosome 10

Gene: SILV (silver), also called PMEL17 (melanocyte protein 17)

Alleles: **M**, **m**

In Shelties:

- ⌘ **MM** – double or homozygous merle
- ⌘ **Mm** – blue merle, bi-blue, sable merle
- ⌘ **mm** – non-merle

How It Works:

The merle gene affects the shade of eumelanin pigment, which is otherwise black in Shelties. The homozygous **MM** dog is predominantly white, is frequently deaf, and sometimes has vision problems.

In the heterozygous **Mm dog**, commonly called a blue merle (or bi-blue), some of the black is altered, resulting in irregular patches of black and gray. Some researchers think there is a tendency for **Mm** merles to have more extensive white markings on their bodies than do non-merles.

The homozygous **mm** is a non-merle.



Figure 4. The merle pattern affects the black hairs of **a^t**, **a^y** and **a** dogs to produce blue merles (left), bi-blues and sable merles (right). In many sable merles, the merling is much less obvious than in the bitch pictured above.

At The DNA Level:

In merle dogs, the SILV or PMEL17 gene has a sequence of DNA called a SINE insertion, inserted into the chromosome at a position where the protein-coding DNA adjoins the non-coding DNA. The **MM** double merle has two copies of this SINE insertion (homozygous), the **Mm** dog has one copy, and the **mm** has none.

An alternate form of the SINE insertion has been identified at the DNA level in some non-merle Shelties descended from merles. Apparently, the SINE insertion is sometimes shortened during DNA replication to result in an inactive **M** gene. This change in the SINE insertion prevents the merle pattern from appearing. A dog with only the shortened form of the insertion is, for all practical purposes, an **mm** non-merle, and is unlikely to pass on merling to his offspring. This is one possible explanation for the occasional tricolor sired by a double merle **MM** dog. The more common reason for an apparent tricolor to be sired by a double merle is that the offspring is in fact a cryptic merle.



Figure 5. Homozygous or double merles, such as the Shelties above, vary in the amount of color on their bodies, but they generally have much less color than a heterozygous merle.

Gene Interactions:

The **M** gene affects eumelanin black or brown pigment. The **M** gene modifies the eumelanin of each of the **A** series alleles, with the merling showing only in the black or black-tipped portions of the coat. Sable merle Shelties have an **Mm** genotype with at least one **a^y** allele. Red merle Australian Shepherds are merled because their red color is brown eumelanin, and not sable phaeomelanin.

Cautions and Comparisons:

There is some overlap in the amount of color between double merles and normal blue merles. In Great Danes and Australian Shepherds, an occasional dog, who appears to be a heterozygous merle, has been proven by DNA testing to be a double merle. It is reasonable to assume that this may occur, if only rarely, in Shelties.

Since the amount and pattern of merling in the black coat appears to be random, it is also unsurprising that occasional **Mm** dogs have minimal or no merling in their coats. These dogs, commonly called cryptic merles, can and do pass merling on to their offspring. I once asked an Australian Shepherd fancier if cryptic merles occurred in that breed. Her answer was, "Yes, and sometimes the merle comes off with the tail dock."

Unfortunately, the scientific literature is inconsistent in its use of the term "cryptic merle", sometimes using it to refer to dogs who carry the shortened inactive form of the SINE insertion, and who therefore do not have and do not normally produce the merle phenotype.



Figure 6. Is she or isn't she? At first glance, this cryptic merle appears to be a bi-black, but a bit of merling shows over the top of her back.

Health Concerns:

Melanocytes, the cells that produce pigment, must be present in the inner ear for normal hearing to develop. It is not necessary to have pigmented hair on the external ears. Since they are predominantly white dogs, most **MM** double merle Shelties lack these inner ear melanocytes, and are deaf. Some have vision defects. A heterozygous **Mm** blue merle Sheltie generally has normal hearing and vision.

While merle deafness occurs in many breeds, the **mm** double merle Catahoula Leopard Dog is more likely to have normal hearing. This may be because these dogs are generally much more heavily pigmented than double merles of other breeds, and are more likely to have melanocytes in the inner ear.

M Series References:

- ⌘ [Clark LA, Wahl JM, Rees CA, Murphy KE. 2006. Retrotransposon insertion in SILV is responsible for merle patterning of the domestic dog. Proc Natl Acad Sci U S A. 103:1376-1381.](#)
 - ⌘ [Hédan B, Corre S, Hitte C, Dréano S, Vilboux T, Derrien T, Denis B, Galibert F, Galibert MD and André. 2006. Coat colour in dogs: identification of the Merle locus in the Australian shepherd breed. BMC Veterinary Research 2:1-10.](#)
 - ⌘ [Strain GM, Clark LA, Wahl JM, Turner AE, Murphy KE. 2009. Prevalence of Deafness in Dogs Heterozygous or Homozygous for the Merle Allele. 23:282-286.](#)
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S series (Spotting and White Markings)

Where: Canine chromosome 20

Gene: MITF (microphthalmia-associated transcription factor)

Alleles: S, s

In Shelties:

- ⌘ **SS** – Irish markings, not white factored
- ⌘ **Ss** – white-factored
- ⌘ **ss** – color-headed white

How It Works:

The **S** gene affects the amount and distribution of white markings, by affecting the migration and survival of melanocytes, the pigment-producing cells, before and shortly after birth. Unlike the **S** series postulated by Clarence Little, this gene appears at present to have only two alleles.

Shelties who are **SS** (non white-factored) have the usual Irish markings: white undersides, legs, chest, with varying amounts of white around the neck and on the face.

The **S** allele is considered to be an incomplete dominant, because the Sheltie who is heterozygous **Ss** (white-factored) typically, but not always, has more extensive white markings, which may extend farther up the sides of the body, and usually includes white up the front of the stifles. However, the amount of white is generally within the range permitted by the breed standard.

The **ss** Sheltie (color-headed white) has a colored head, with a predominantly white body and varying irregular patches of body color.



Figure 7. The extent of Irish-white markings is highly variable, but includes the underside of the body, the chest, and varying amounts of white around the neck, on the face, and on the legs. The Irish-white markings are not yet explained by the known **S** series alleles.

At The DNA Level:

The **s** allele appears to be due to the insertion of a short sequence of DNA (another SINE element) into the MITF gene shortly before the first location that is transcribed into the MITF protein. **SS** dogs, lacking the insertion, have typical Irish-white markings. At this time, no changes in the MITF gene have been clearly identified that explain the Irish-white markings found to a greater or lesser extent in all Shelties. Other than the SINE insertion, no changes have been identified that explain the wide differences in the extent of Irish-white markings.



Figure 8. Both these Shelties are white-factored, but only the one on the left shows significant white stifle markings..

Gene Interactions:

The **S** series white hides all colors, but does not change the nature of the “invisible” color. Thus, a dog who has ticking (**T** series) will have tan ticking in the areas that would be tan if the white did not prevent color, and black ticking in the areas that would be otherwise be black.

Cautions and Comparisons:

The white markings seen in flashy Boxers and in mantle Great Danes are not true Irish-white markings, but are the result of the heterozygous **Ss** genotype. In the white-factored Sheltie, this pseudo-Irish pattern is superimposed on the pre-existing fixed Irish-white.

A Sheltie with a small white body spot is not necessarily white-factored, as the migration of melanocytes can be somewhat affected by the environment of the unborn puppy in the uterus.

Not all white-factor markings are explained by the SINE insertion in the MITF gene. Researchers found that a few individual dogs of several breeds had white-markings that were not predicted by their MITF genotype.

And in one family of Icelandic Sheepdogs, where the parentage was verified by DNA testing, the amount of white markings had no relation to their MITF genotype. Since the Sheltie is likely related to the Icelandic Sheepdog, it is possible that an additional gene or mutation may also be responsible for producing color-headed white Shelties. This



Figure 9. Color-headed white Shelties can have sable, tricolor, bicolor, blue merle, or even sable merle markings.

could potentially be one reason why some white-factored Shelties do not show the typical white stifle markings.

No DNA change has yet been identified that explains the occasional Sheltie who has one side of the face entirely white, or that explains the extent of white blazes on the face. Research on white markings continues, and hopefully will clarify the inheritance of these patterns in the future.

Health Concerns:

The presence of melanocytes in the inner ear is required for the development of normal hearing. Thus, color-headed white Shelties have normal hearing because they have enough color. The melanocytes present in the skin of the head are usually also present in the inner ear so that normal hearing develops.

If they have white heads, white Shelties would be expected to have an increased incidence of deafness, such as occurs frequently in white boxers. Some white breeds, such as Samoyeds, appear to be white by an entirely different mechanism, and in these breeds, melanocytes are present in the inner ear, and white-related

deafness is not a problem.



Figure 10. Although the genotype of a white and merle dog can usually be told by his parentage or by his appearance, there is occasionally some overlap. The bitch on the left is a heavily pigmented double merle, with normal vision and hearing. The dog at right is a normal blue merle-headed white-factor white.

S Series References:

- ε [Karlsson EK, Baranowska I, Wade CM, Salmon Hillbertz NHC, Zody MC, Anderson N, Biagi TM, Patterson N, Rosengren Pielberg G, Kulbokas EJ III, et al. 2007. Efficient mapping of Mendelian traits in dogs through genome-wide association. Nat Genet. 39:1321–1328.](#)
- ε [Peter A., Van Hagen, Marjan A, Van Oost, Bernard A. 2007. Localization of White Spotting Locus in Boxer Dogs on CFA20 by Genome-Wide Linkage Analysis with 1500 SNPs. Journal of Heredity 98 \(5\):549-552](#)
- ε [Rothschild MF, Van Cleave PS, Carlstrom LP, Glenn KL, Ellinwood NM. 2006. Association of MITF with white spotting in Beagle crossed dogs and Newfoundland dogs. Anim Genet. 37:606-607.](#)
- ε [Schmutz, Sheila M, Berryere, Tom G., Dreger, Dayna L. 2009. MITF and White Spotting In Dogs: A Population Study. Journal of Heredity 100 \(Supplement 1\):S66-S74](#)
- ε [Strain, GM. 2004. Deafness prevalence and pigmentation and gender associations in dog breeds at risk. Veterinary Journal 167: 23-32.](#)

Other Sheltie Color Genes:

B series (Brown/Liver/Chocolate)

Where: Canine chromosome 11

Gene: TYRP1 (P1 (Tyrosinase related protein 1))

Alleles: B, b

In Shelties:

- ε **BB** – With rare exception, Shelties are fixed for the dominant **B**. Their eumelanin is black instead of brown.

How It Works:

The **B** series alleles determine whether the eumelanin of the dog is black or brown. The dominant **B** has black eumelanin and the recessive **bb** has brown eumelanin. Any of three different mutations can be present, but any combination of two of them results in eumelanin that is brown rather than black in both skin and hair.

At the DNA Level:

Dominant **B** is the ancestral form of the gene. One mutation (**b^s**) is a substitution of thymidine for cytosine, which results in an instruction to stop adding amino acids to an unfinished protein (a premature stop codon, Q331ter). A second mutation (**b^d**) deletes three base pairs, resulting in the deletion of a proline amino acid

(345delP) from the resulting protein. A third, less common, variant (**b^c**) results in a substitution of the amino acid serine for cysteine in the resulting protein (S41C). Any combination of two of these mutations alters the synthesis of eumelanin so that the dog is brown instead of black.

Gene Interactions:

When the **B** series genotype is **bb**, all sables, tricolors, merles and brindles, as well as dogs with **E^m** masked muzzles, will have the black hairs or black portions of the hair replaced by brown.



Figure 11. This tricolor rescue Sheltie is chocolate, tan and white. His nose and eye rims are also chocolate brown.

Cautions and Comparisons:

The name given to the brown coat, as well as the shade of brown, varies widely among breeds of dogs. Thus, brown Newfoundlands, chocolate Labrador Retrievers, liver Pointers, and red Australian Shepherds are all **bb** dogs. Red is an especially confusing term since it is used in different breeds for both eumelanin and phaeomelanin.

Since the brown color is eumelanin, merle (**M**), gray dilute (**dd** genotype) and brindle (**k^{br}**) can also act on it to result in red merle Australian Shepherds, lilac Border Collies and brown brindles of many breeds.

The occasional brown tricolor Sheltie is either the result of a mutation or of a rare (in Shelties) homozygous recessive.

Health Concerns:

None known.

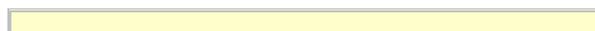
B Series References:

- ⚡ [Cargill EJ, Famula TR, Schnabel RD, StrainGM, Murphy KE. 2005. The color of a Dalmatian's spots: Linkage evidence to support the TYRP1 gene. BMC Veterinary Research 1: 1-5.](#)
- ⚡ [Schmutz SM, Berryere TG, Goldfinch AD. 2002. TYRP1 and MC1r genotypes and their effects on coat color in dogs. Mamm Genome. 13:380-387.](#)

C series (Chinchilla, Albino)

Gene: unknown

Hypothetical Alleles: C, c^{ch}, c^a



In Shelties:

- ε **CC** – Shelties appear to be fixed for the dominant, so that the coat is a full rich color.

How It Works:

The existence of the **C** series in dogs is in question. It was described by Clarence Little as being the same as the **C** series in mice, which is now known to be the effect of the Tyrosinase gene. This gene has been investigated, but so far its variations have not been associated with variations in dog coat color.

According to Little, the dominant **C** is associated with full, rich coat color of most dogs. The **c^{ch}** allele, in the absence of **C**, would be responsible for lightening the color of both eumelanin and phaeomelanin. In mice, the recessive, **c^a**, is a pink-eyed albino. Although intensity of color certainly varies in the dog, the existence of these variations as alleles of the Tyrosinase gene is questionable.

D series (Gray Dilution, Blue Dilution)

Where: Canine chromosome 25

Gene: MLPH (melanophilin)

Alleles: D, d

In Shelties:

- ε **DD** – Non-dilute.
The dog has black eumelanin in its coat and a black nose.
- ε **Dd** – Non-dilute, but a carrier of the dilution allele.
- ε **dd** – Grey dilute, sometimes called Maltese blue.
The black of tricolors and bi-blacks is diluted to a uniform gray. This recessive dilution can also affect the otherwise black hair of sables and blue merles. There is much less effect on the shade of tan/sable.

How It Works:

The recessive **dd** genotype causes the black pigment to be clumped, rather than evenly distributed through the hair and skin. This results in the appearance of gray rather than black. Typically, the nose and eye rims are also gray. Some dilute Shelties have black noses, and it is uncertain whether these dogs have the **dd** genotype or some other dilution gene.

At The DNA Level:

The most likely candidate for the **d** allele is a DNA mutation resulting in a single substitution of adenine for guanine (c.-22G>A) in a non-protein-coding portion of the MLPH gene.

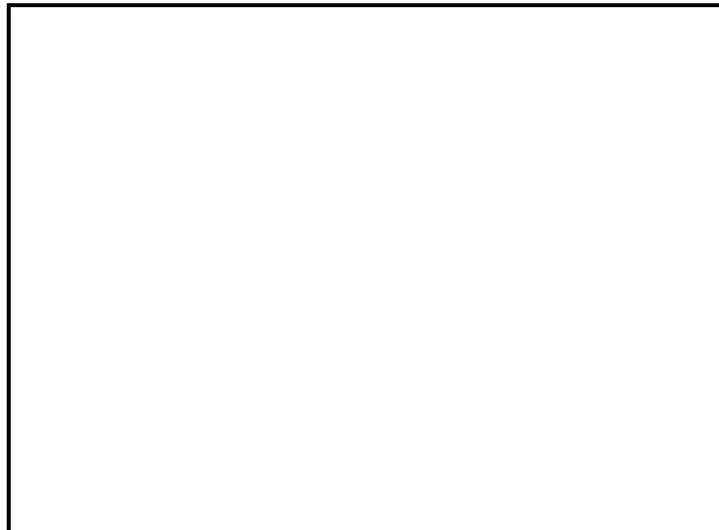




Figure 12. This puppy is a dilute tricolor. He is not a merle. His black hair has been diluted to a uniform gray.

Gene Interactions:

The recessive **dd** acts on any eumelanin in the coat and skin. The **a^y** sables are tan with interspersed gray and gray-tipped hairs. Tricolors will have gray coats and possibly slightly paler tan points. The **dd** genotype can also act on **bb** liver/brown dogs to cause a dilute brown, called lilac in Border Collies and Isabella in Doberman Pinschers.

Cautions and Comparisons:

The term “Maltese blue” was used by Clarence Little in reference to the **dd** dilution. Since this is a popular, not a scientific term, it has sometimes been used with other meanings.

The **D** series phenotypes are fixed at birth. It should not be confused with the **G** gene, which results in progressive graying of a black coat as the dog matures. The **D** series dilution is not related to merle in any way, although it can also act on merle dogs.

The **dd** genotype is uncommon in Shelties, but the color shows up periodically as the result of breeding two unsuspected carriers of the recessive. The color has not been investigated in Shelties, and it is possible that it is not due to the same mutation as in the breeds that have been investigated.

The **dd** gray color should not be confused with the grayish coloring associated with cyclic hematopoiesis (cyclic neutropenia, or lethal silver). Lethal silver, also called Gray Collie Syndrome, occurs in collies and may occur in Shelties, but is caused by an entirely different gene. Dilute **dd** dogs have a healthy immune system, and are expected to have a normal life span.

Health Concerns:

Probably none in Shelties. In some other breeds, the blue or gray coat is associated with a medical problem called color dilution alopecia. This condition, which results in hair loss in the areas with diluted color, is more likely to occur when the melanin is clumped in the epidermis of the skin, rather than just in the hair and in the epithelium lining the hair shaft. The condition does not appear to be seen in color dilute Shelties.

D Series References:

- ⌘ [Drögemüller C, Philipp U, Haase B, Günzel-Apel AR, Leeb T. 2007. A non-coding melanophilin gene \(MLPH\) SNP at the splice donor of exon 1 \(c.-22G.A\) represents a candidate causal mutation for coat color dilution in dogs. J Hered. 98:468-473.](#)
- ⌘ [Philipp U, Hamann H, Mecklenburg L, Nishino S, Mignot E, Günzel-Apel AR, Schmutz SM, Leeb T. 2005. Polymorphisms within the canine MLPH gene are associated with dilute coat color in dogs. BMC Genet. 6:34.](#)
- ⌘ [Philipp U, Quignon P, Scott A, Andre C, Breen M, Leeb T. 2005. Chromosomal assignment of the canine melanophilin gene \(MLPH\): a candidate gene for coat color dilution in Pinschers. J Hered. 96:774-](#)

E series (Extension)

Where: Canine chromosome 5

Gene: MC1R (Melanocortin 1 Receptor, formerly Melanocyte Stimulating Hormone Receptor)

Alleles: E^m, E^g, E, e

In Shelties:

⊘ **EE – Shelties are fixed for the E allele. Recessive yellow does not occur.**

How It Works:

Like the **A** series and the **K** series, the **E** series controls the amount and distribution of phaeomelanin (yellow/tan) pigment in the coat, by regulating a switch between eumelanin and phaeomelanin in different parts of the coat. The dominant **E^m** gene forces a black mask covering the muzzle of the dog, while the rest of the coat color is determined by the **K** series and the **A** series. The **E^g** allele causes grizzle Afghans and domino Salukis. It is expressed only in dogs who are also **a^ta^t** at the A locus. **E^g** is recessive to **E^m**, but dominant over **E** and **e**. The **E** allele, in the absence of **E^m** or **E^g**, allows the full expression of the **K** series and the **A** series colors. The recessive **ee** genotype results in a coat that is completely yellow/red, although black pigment remains in the skin.

At The DNA Level:

The DNA changes resulting in the dominant **E^m** mask cause one substitution of the amino acid valine for methionine (M264V) in the MC1R protein, as compared to the **E** phenotype. The **E^g** allele is the result of a mutation that causes the substitution of valine for glycine in the resulting protein (p.Gly78Val). The recessive **ee** is caused by a gene change that results in a shortened protein. The mutation is a DNA substitution which results in an instruction (a premature stop codon) to stop adding amino acids to an unfinished protein (R306ter).

Gene Interactions:

E^g is epistatic to **a^ta^t** and hypostatic to **a^y** and **K**, so that the phenotype only shows in **a^ta^t** individuals. The recessive **ee** is epistatic to the **A** series gene and prevents any expression of **A** series alleles. In the presence of **ee**, the effects of the **B** series brown and the **D** series blue dilution and the **M** series merling cannot be seen in the hair. However, the **ee** genotype does not prevent these genes from showing their effects on eye and skin color. The **ee** genotype prevents expression of dominant black and brindle. Little considered brindle to be part of the **E** series. However, recent research has re-assigned both brindle and dominant black to the **K** series.

Cautions and Comparisons:

Labradors, Golden Retrievers, Irish Setters and cream-colored dogs of many breeds have been found to have the **ee** genotype. The **ee** yellow/red/tan/fawn phaeomelanin should not be confused with **B** series brown/liver/chocolate eumelanin, which it sometimes resembles. In most cases the color of the nose will tell them apart. In some breeds both **ee** and **a^y** fawns occur, and it is impossible to tell them apart by their appearance.

Health Concerns:

None known.

E Series References:

- ⊘ [Dreger DL, Schmutz SM. 2010 A New Mutation in MC1R Explains a Coat Color Phenotype in 2 "Old" Breeds: Saluki and Afghan Hound. J Hered 101. 644-649.](#)
- ⊘ [Everts RE, Rothuizen J, van Oost BA. 2000. Identification of a premature stop codon in the melanocyte stimulating hormone receptor gene \(MC1R\) in Labrador and Golden retrievers with yellow coat colour. Anim Genet 31, 194-199](#)
- ⊘ [Kerns JA, Olivier M, Lust G, Barsh GS. 2003. Exclusion of melanocortin-1 receptor \(Mc1r\) and agouti as candidates for dominant black in dogs. J Hered 94. 75-79](#)

- ε [Newton JM, Wilkie AL, He L, Jordan SA, Metallinos DL, Holmes NG, Jackson IJ, Barsh GS. 2000. Melanocortin 1 receptor variation in the domestic dog. Mamm Genome 11, 24-30](#)
 - ε [Oguro-Okana M, Honda M, Yamazaki K and Okano K. 2011. Mutations in the Melanocortin 1 Receptor, β-Defensin103 and Agouti Signaling Protein Genes. Their Association with Coat Color Phenotypes in Akita-Inu Dogs. Journal of Veterinary Medical Science 73, 853-858.](#)
 - ε [Schmutz SM, Berryere TG. 2007. The Genetics of Cream Coat Color In Dogs. J Hered 98, 544-548](#)
 - ε [Schmutz SM, Berryere TG, Ellinwood NM, Kerns JA, Barsh GS. 2003. MC1R studies in dogs with melanistic mask or brindle patterns. J Hered 94, 69-73](#)
 - ε [Schmutz SM, Berryere TG, Goldfinch AD. 2002. TYRP1 and MC1r genotypes and their effects on coat color in dogs. Mamm Genome. 13:380-387.](#)
-

G series (Progressive Graying)

Gene: Unidentified

Alleles: G, g

In Shelties:

- ε **gg** – Shelties are fixed for the recessive. Progressive graying does not occur.

How It Works:

The gene responsible for this color change has not been identified. The apparently dominant **G** allele results in a dog who is born black, but who gradually fades to gray in the first year or two of his life. The recessive **gg** results in a dog whose color does not fade.

Gene Interactions:

This gene should not be confused with the **D** series, whose recessive, **dd**, is born gray and remains so.

Cautions and Comparisons:

This is the graying gene of Kerry Blue Terriers and a few other breeds.

Health Concerns:

None known.

H series (Harlequin)

Where: Canine chromosome 9

Gene: PSMB7

Alleles: H, h

In Shelties:

- ε **hh** – Non-harlequin
- ε **Hh ?** – Harlequin phenotype is rare in the Sheltie, and is probably not due to the same mutation that occurs in Great Danes.

How It Works:

Harlequin, always heterozygous **Hh**, acts only in the presence of **M** series merling to dilute the gray portions of the merle coat to white. The recessive **hh** is a non-harlequin, which may be a blue merle.

At The DNA Level:

The harlequin phenotype is the result of a substitution of a single nucleotide in the PSMB7 gene, which results in the amino acid glycine replacing valine in the resulting protein (p.Val49Gly). This mutation may act by impairing necessary breakdown of proteins.

Gene Interactions:

The color effects of the harlequin gene are seen only in the presence of the merle gene. A dog who is a K series non-merle black will not be harlequin even if he carries the harlequin gene.

Cautions and Comparisons:

Whether the occasional merle Sheltie whose gray is diluted almost to white is a true harlequin is unknown, but if so, the mutation is probably different from that which occurs in Great Danes.

Health Concerns:

The homozygous **HH** genotype in Great Danes is lethal to the embryo. Double harlequins are not born, and litters that are expected to produce them contain fewer puppies.

H Series References:

- ⌘ [Clark LA, Starr AN, Tsai KL, Murphy KE. 2008. Genome-wide linkage scan localizes the harlequin locus in the Great Dane to chromosome 9. *Gene* 418: 49-52.](#)
 - ⌘ [Clark LA, Tsai KL, Starr AN, Nowend KL, Murphy KE, 2011. A missense mutation in the 20S proteasome B2 subunit of Great Danes having harlequin coat patterning. *Genomics* 97\(4\):244-8.](#)
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K series (Dominant Black, Brindle, and Tan)

Where: Canine chromosome 16

Gene: β -defensin 103

Alleles: K^B , k^{br} , k^y

In Shelties:

- ⌘ $k^y k^y$ – With possible rare exceptions, Shelties are fixed for the recessive k^y , which allows full expression of the A series phenotypes.

How It Works:

The **K** series is a newly recognized color gene, that was not identified by Clarence Little. It is one of the β -defensin genes, which are generally involved in immune function and have not previously been associated with coat color in animals. The **K** series is responsible for the dominant black that Little assigned to the **A** gene. Brindle color, assigned by Little to the **E** gene, segregates perfectly as an intermediate allele of the **K** series. The **K** series, like the **A** series and **E** series, is involved in pigment switching between eumelanin black and pheomelanin tan. Dogs with at least one copy of the dominant K^B allele will be black in all pigmented areas of their body. Recessive to K^B is k^{br} , which in the absence of K^B results in brindle in the parts of the coat that are tan because of their **A** series alleles. The most recessive allele is k^y , which allows tan/sable, as determined by the **A** series alleles.

At The DNA Level:

The k^y allele appears to be the ancestral allele in this series. The K^B allele is associated with a deletion in the DNA, that causes a glycine amino acid ($\Delta G23$) to be missing from the resulting protein. However, it appears the $\Delta G23$ deletion is not exclusively associated with the K^B allele, as it appears in some brindle dogs. Although the k^{br} mutation has not been specifically located, brindle color segregates as an intermediate allele in the **K** series.

Gene Interactions:

The **K** series black is epistatic to the **A** series, and in the presence of a K^B allele, the dog will be black regardless of its **A** series alleles. Both k^{br} and k^y allow expression of the **A** series alleles. But if the dog is $k^{br} k^{br}$ or $k^{br} k^y$, he will be brindle in any areas of **A** series tan. Thus an a^y dog would be brindle, and an $a^t a^t$ dog would be black with brindle points.



Cautions and Comparisons:

K^B produces the common black of Border Collies, but is not found in Shelties. In view of the dominance of k^{br} allele over the k^y allele, the Sheltie breed standard's disqualification for brindle makes perfect sense. Unless a brindle Sheltie is the result of a new mutation, or the unlikely result of brindle being hidden through multiple generations of bicolors, a brindle Sheltie, because of its genetics, is unlikely to be purebred. Since a mutation responsible for brindle has not been identified, explanations of the **K** series, especially of brindle, are incomplete, and may be modified by the findings of future research.

Health Concerns: None known.



Figure 13. According to our current understanding, a Sheltie cannot have a hidden brindle allele unless it is a bicolor. But occasional brindle dogs show up who appear to be Shelties. If they are, in fact, purebred Shelties, either our understanding of brindle inheritance is incomplete, or their color is the result of mutation.

K Series References :

- ε [Candille SI, Kaelin CB, Cattanach BM, Yu B, Thompson DA, Nix MA, Kerns JA, Schmutz SM, Millhauser GL, Barsh GS. 2007. A \$\beta\$ -Defensin Mutation Causes Black Coat Color in Domestic Dogs. *Science*. 318: 1418-1423](#)
- ε [Kerns JA, Cargill EJ, Clark LA, Candille SI, Berryere TG, Olivier M, Lust G, Todhunter RJ, Schmutz SM, Murphy KE, Barsh GS. 2007. Linkage and Segregation Analysis of Black and Brindle Coat Color in Domestic Dogs. *Genetics* 176: 1679-1689.](#)
- ε [Oguro-Okana M, Honda M, Yamazaki K and Okano K. 2011. Mutations in the Melanocortin 1 Receptor, \$\beta\$ -Defensin103 and Agouti Signaling Protein Genes, Their Association with Coat Color Phenotypes in Akita-Inu Dogs. *Journal of Veterinary Medical Science* 73, 853-858.](#)

T series (Ticking)

Gene: Unidentified

Alleles: T, t

In Shelties:

- ε **TT – ticked – flecks of color appear in the otherwise white portions of the coat.**
- ε **Tt – ticked, but a heterozygous carrier of non-ticked (possibly less ticking)**
- ε **tt – non-ticked – no ticking**

How It Works:

T series ticking allows the development of colored flecks or spots on areas of the dog that would otherwise

be white. It appears to be dominant, or possibly an incomplete dominant.

Gene Interactions:

Ticking appears in the parts of the coat that are white due to the **S** series. The color of the ticking is determined by the other color genotypes present. The dog who has **T** series ticking will have tan ticking in the areas that would be tan if the white did not prevent color, and black ticking in the areas that would be otherwise be black.



Figure 14. This Sheltie has significant ticking on her legs and fore face.

Cautions and Comparisons:

Ticking is not an all or none phenomenon, and Shelties never have the degree of ticking that appears in English Setters. Ticking is not evident at birth, but gradually appears as the dog matures.

Heavy ticking should not be confused with merling. Merling is present at birth in the colored portions of the coat. Ticking develops after birth in the white portions of the coat.

Australian Cattle Dogs are probably ticked, or perhaps roaned, but not merled. It is unknown whether the roan color that appears in Setters and some Spaniels is the same as ticking or not.

Health Concerns:

None known.

Series	Name	Colors	Alleles	Gene	Chromosome
A series	Agouti	Sable <i>Agouti</i> Tricolor Bicolor	a^y a^w a^t a	agouti signal protein (ASIP)	24
B series	Brown	Black <i>Brown (liver, red, chocolate)</i>	B b	tyrosinase related protein 1 (TYRP1)	11
C series	Chinchilla	Full color <i>Lightened color</i> <i>Albino</i>	C c^{ch} c^a	tyrosinase (TYR) (associated with color in mice, but not in dogs)	NA
D series	Dilution	Black (or brown) Gray (or lilac)	D d	melanophilin (MLPH)	25
E series	Extension	<i>Masked</i> <i>Grizzle/Domino</i> Non-masked <i>Yellow, cream, red</i>	E^m E^g E e	melanocortin 1 receptor (MC1R)	5
G	Graying	<i>Progressive graying</i>	G	unidentified	unidentified

series		No graying	g		
H series	Harlequin	<i>Harlequin</i> Non harlequin	<i>H</i> h	PSMB7	9
K series	Dominant black	<i>Dominant black</i> <i>Brindle</i> Fawn/sable	<i>K^B</i> <i>k^{br}</i> <i>k^y</i>	β-defensin 103 (beta-defensin 103)	16
M series	Merle	Merle Non-merle	M m	silver (SILV), also called melanocyte protein 17 (PMEL 17)	10
S series	White spotting	Irish-white marked Color-headed white	S s	microphthalmia-associated transcription factor (MITF)	20
I series	Ticking	Ticked Non-ticked	T t	unidentified	unidentified

Table 1. Identified or hypothesized color genes of the dog. Colors and alleles in gray italics are absent or rare in the Sheltie.

Other Possible Genes:

Other genes have been suggested to explain various shades of eumelanin and phaeomelanin, but none has been clearly identified. Researchers suspect that at least one unknown gene is responsible for lightening the color of phaeomelanin tan without affecting eumelanin black, and that another gene may affect the shades of both eumelanin and phaeomelanin equally. And if shaded sables are not necessarily tri-factored or bi-factored, why are some sables shaded and others not? If the same **ss** genotype results in white boxers and color-headed white Shelties, what gene is responsible for the consistent colored head of the Shelties? What other genes are gene involved in white factoring? What gene is responsible for the Irish white markings? Hopefully, the answers to these and other questions will be forthcoming in the near future.

Answers to Figure 3:

Shelties B, C & E are tri-factored.
Shelties A & D are pure for sable.
Sheltie F is bi-factored.
B and E are the same Sheltie,
with three years between the photos.

Dogs Pictured:

Figure 1: (left) GCh LorraLee's Midnight Special, Anita Rasmussen, (right) Ch Sea Haven Bi Moonrise, Yvonne Samuelson.

Figure 3: (A) Ch Sagebrush Ceili Music TD CD RN HT MX MXJ VCX, (B) Ch MACH Apple Acres Sagebrush Kerry TD PT VCX, (C) Sagebrush Sally Garden, Kevin & Kathy Dill, (D) GCh Sagebrush Little Big Man PT MX MXJ VCX, (E) Ch MACH Apple Acres Sagebrush Kerry TD PT VCX, (F) Ch Sagebrush Jolee Golden Dreamer PT AX AXJ VCX, Alicia Keegan

Figure 4: (left) Ch Icon Valley View Holy Smoke, Diane LaClare, (right) Kensil's Material Girl, Locklyn Guzman.

Figure 5: (left) Lacewood Ghost Star, Tricia Harris, (right) Granite Gables Crystal Mist, Rose Marie Doran.

Figure 6: Apple Acres Filtered Light, Locklyn Guzman.

Figure 7: (left) Ch Lorra Lee's Ready To Rumble, Anita Rasmussen, (right) Apple Acres Sagebrush Raven, TDX PT OA NAJ, Alicia Keegan

Figure 8: (left) Apple Acres Blue Heaven Jasmine, Locklyn Guzman, (right) Wind Dancer's Bayleigh-N-Cream, Karen Ritchie.

Figure 9: (top) U-Gr-Ch Dark Star's Indian Scout, Karen Ritchie, (middle) U-Ch Premiere's Animal Crackers, Karen Ritchie, (Bottom) Waldenwood Penny's from Heaven UD PT AX AXJ RE, Susan Guy.

Figure 10: (left) Granite Gables Crystal Mist, Rose Marie Doran, (right) U-Ch Apple Acres Lion In Winter, Karen Ritchie.

Figure 11: Rescue Sheltie, Dorothy Christiansen.

Figure 12: Puppy, Judy Decker.

Figure 13: Rescue Sheltie, Dorothy Christiansen.

Figure 14: Ch Up A Shade Ada JHD, Donna Shade.

Thank you to the owners of these Shelties for making their photographs available to us.

About The Author:

Alicia Keegan is a practicing veterinarian and a 37 year ASSA member. She holds a BA degree in biology, and a DVM degree. Over the years, she has worked with numerous fanciers of many breeds, and has always had a special interest in genetics. She recalls one misunderstanding of genetics that had a breeder of field Labradors convinced that mating a yellow bitch to a chocolate dog would result in only yellow and chocolate puppies. She could not convince him otherwise, and the breeder was amazed at the resultant litter of black puppies. Alicia breeds, trains and shows Shelties in all venues under the Sagebrush prefix.
